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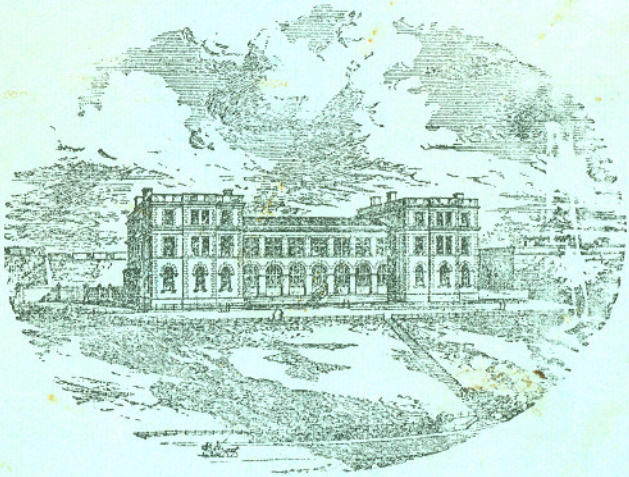

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Summary of an Account of Investigations into the Cause or Causes of the Unusual Mortality among Oysters in English Oyster Beds during 1920 and 1921.

Compiled from CHEMICAL REPORTS BY

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Bacteriological Reports by Prof. J. Eyre.

Biological Investigations by J. H. Orton, D.Sc.

By

J. H. Orton, D.Sc.

(*Assisted in Laboratory Work by Miss EDITH WORSNOP, M.Sc.*)

CONTENTS

PREFACE.

On October 28th, 1920, a conjoint meeting was held by representatives of the Development Commission, the Ministry of Agriculture and Fisheries and the Oyster Merchants and Planters Association to institute investigations into the cause of the abnormal mortality which had occurred among oysters in the oyster beds in the Thames Estuary during the summer of 1920. As a result of this meeting investigations were begun under the general direction of the writer. On the completion of the work a full report of the results obtained was forwarded to the Fisheries Department, Ministry of Agriculture and Fisheries. The more important parts of that report will be published as follows: Part I, Main Report, Fishery Investigations, Ministry of Agriculture and Fisheries, London, Series II, Vol. VI, No. 3, 1923; Part II. containing the more important Appendices, will appear later.

SUMMARY.

Normal Mortality and Review of Literature on Oyster Mortality, Diseases and Pests.

The investigations herein described relate to the European oyster (*Ostrea edulis*) unless otherwise noted.

The normal mortality of oysters on English oyster-beds is estimated by oyster-planters at 10 per cent in locally grown oysters, and at least 15 per cent in relaid oysters, and is stated to occur chiefly in summer. It has been found that the bulk of the mortality does actually occur in summer, and is correlated with the spawning period.

Heavier mortality than is usual may occur in or follow severe winters.

There is some reason to believe that unusual mortality which has been attributed vaguely to physical causes—apart from the effects of severe frost—may have occurred formerly on English oyster beds.

Dutch oyster planters consider a 20 to 25 per cent mortality normal, and Hoek has shown that on some occasions the summer mortality has reached higher levels, estimated at upwards to 50 per cent. Figures given so far for mortality in the sea are estimations and not accurate determinations.

Holt's experiments on the West of Ireland—carried out admittedly under disadvantageous conditions—resulted in very heavy mortalities in the *second* year after relaying, and agree in this respect with Hoek's experience.

These findings are important, and show that *in relaid oysters an induced physiological weakness, due to unfavourable conditions during and/or after relaying, may or may not show itself in a high mortality rate during the*

first summer after relaying, while a very high rate of mortality may occur in the second summer after relaying.

It is not inferred that high mortalities follow all relayings.

The cause of the bulk of the the mortality has in no case been assigned definitely, but there is a vague, tacit indication in the writings of workers that fundamental functional disturbances are suspected, while here and there a suspicion of parasites is mentioned without however offering any valid ground for this suspicion. No evidence exists anywhere of any bacterium or Protozoan or allied internal parasite causing the death of oysters in the sea. Many predatory enemies of oysters are known and recognised, but the extent of the depredations is not accurately known and must necessarily vary. Great variations in saltness of water over oyster-beds are known to induce weakness or cause death of oysters, and great variations in salinity and temperature at about the spawning period are believed to be dangerous to the health of oysters. Ice-cold water if of low salinity is also known to be specially harmful to oysters.

There can be no doubt therefore that different oyster beds will have different mortality rates, and that the rates will vary with the local physical conditions, the presence or absence of pests, and finally the method of cultivation.

Abnormal Mortality Reported Among Oysters in Europe, 1919–21.

A great mortality of oysters was reported from the region of Taranto, South Italy, during the winter of 1919–20. No report of investigations in that area has been published at the moment of writing, but reports have been received by letter that a filiform bacterium, obtained in1919–20 from dying oysters, causes death of oysters when added in cultures to oysters in small vessels. Further evidence is required to substantiate this statement, and no evidence has been adduced to show that the particular bacterium would be harmful to oysters in the sea. No other cause of the mortality has been detected, but bad condition of the water, due to shipping, to adjacent military camps, and to removal of the hull of the sunken Dreadnought, *Leonardo da Vinci*, is believed to have occurred.

An unusual mortality of oysters was also reported from the beds on the west coast of France, from Morbihan to Cape Finisterre, in 1920, and at these places and others in the English Channel in 1921. No dangerous bacterial or other parasite has been discovered in hockley oysters from these regions, and no explanation of the mortality is put forward, other than the rapid fall in temperature in June, 1920, after previous unusually warm weather. It is reported, however, that oysters wholly grown in

claires did not show unusual mortality, whilst oysters in the sea—and apparently on beds adjacent—did show unusual mortality. It would, therefore, seem clear that temperature variations will not explain the absence of mortality in claires, since the practically stagnant water of the claires would follow atmospheric changes much more closely and quickly than the water in even shallow estuaries.

A mortality of upwards to 70 per cent is reported from oysters dredged at Brest, and 30 per cent at Quiberon, but as in the case of English beds these are estimations, and the normal mortality is not stated. At Arcachon, on January 15/21, it is stated that the mortality fell to 4 per cent, a figure regarded as below the normal, but as this figure is far higher than that estimated for any English oyster bed at any time it would appear that the normal mortality on French beds is much higher than on English beds. No unusual mortality of Portuguese oysters (*O. angulata*) occurred on French oyster beds in 1920.

The mortality reported from Dutch oyster beds in 1920 was also high, but high summer mortalities on these beds are known from previous observations. On the Dutch oyster beds far more attention is paid to salinity and temperature variations than anywhere else. It is known * that in January, 1920, the water was of very low salinity during the greater part of the month, and at times at low water almost drinkable, and there can be no doubt that Dr. Folpmers is right in attributing the mortality observed on these beds to the conditions observed, for the oysters were in very poor condition, as is shown by weight determinations in May and November, 1920. No unusual bacteria were observed in 1920, nor in 1921, on these beds, nor on the Yersche and Bergsche beds, where high mortality also occurred. On the latter beds general neglect and a heavy fall of Ascidian spat, which tended to smother the oysters, are offered with the low temperature (13° C. as against a normal of 21° C.) in August, 1920, as an explanation of the high mortality.

In 1921 there was also an undefined high death rate on the Grevilingen beds which could not be attributed to any of the above causes, but it seems probable that the weakness carried over from the previous year, along with the extended spawning season, is sufficient explanation. The oysters on the Zeeland beds in 1921 are shown by Dr. Folpmers to have been in good condition in June, and to have fattened up well by December.

Reports of unusual mortality in Ireland in 1920 have not been substantiated, but it would appear that there was a slightly higher mortality than usual in many places in 1921, as indeed might be expected. No reports of unusual mortality were received from any other European countries nor from Scotland nor from America in 1920. In England, in

* The following information was kindly given by Dr. Folpmers, Bacteriologist to the Zeeland Fishery Board.

1920, heavy mortality was reported among oysters in the Thames Estuary, the Isle of Wight region, and off Swansea. In 1921 unusual mortality was again reported from beds in the Thames Estuary and from some beds in the neighbourhood of Falmouth, but the conditions on all beds were not reported upon.

Thus unusual mortality of oysters was reported to have occurred in Italy late in 1919, on the west coast of France, the Thames Estuary, and probably also the Isle of Wight and Bristol Channel in the summer of 1920, and after a cessation in all parts in the winter of 1920–21, reports were again received from the Thames Estuary, English Channel and north and west coasts of France of unusual mortality in the summer of 1921. The mortality in Italy was apparently mainly a winter outbreak, that in France apparently mainly summer, that on English beds distinctly a summer phenomenon wherever it has been closely observed. The mortality at Taranto, Brest, in the Thames Estuary and Isle of Wight reaches is in the region of considerable shipping traffic, that at Quiberon Bay and on beds in the English Channel is not.

Mortalities rather greater than usual may be expected to have occurred in 1921 owing to the lengthy hot summer, but those for 1920, although accounted for by some workers and oyster planters as due to the peculiar weather of that year, cannot be regarded definitely as due to weather conditions in the present state of knowledge, and have to be considered in relation to the dumping of munitions in the sea during the immediate post-war period, and in relation to any other factors.

ABNORMAL MORTALITY REPORTED AMONG OYSTERS ON ENGLISH OYSTER BEDS, 1920–21.

A. THAMES ESTUARY AREA.

Investigations on English beds have been conducted largely in the Thames Estuary and are considered under the following sub-divisions :—

(1) Physical Conditions.

The abnormal weather of 1920 was believed by many oyster cultivators to be a likely cause of increased mortality of oysters. A study was made of air temperatures and sea temperatures in the environs of the Thames Estuary ; it was found that the mean surface sea temperature at the Shipwash Light-vessel followed the mean air temperature over the Estuary, almost exactly with a lag-period of about fourteen days when reckoned over a period of thirty-eight years. It is shown that temperatures higher up the Estuary would be higher and would follow the mean air temperature much more closely and quickly than in the lower parts of the Estuary.

Thus mean air temperatures will give a good indication of temperature variations in the sea over oyster beds. Similar temperature variations occurred in the two years 1912 and 1920, except that the mean was higher in July, 1912, and lower in August, 1912, than in the corresponding months in 1920. In a similar manner a study of rainfall indicates that the salinity variations from the average were probably greater in 1912 than in 1920. Thus unusual oyster mortality should have occurred in 1912 if physical conditions were the sole cause. Most oyster planters report normal mortality or no record for 1912, but one or two report much death. It is certain that wherever spawning oysters are subjected to relatively cold water of low salinity for any appreciable length of time increased weakness and mortality would follow. Thus an undeterminable increase in mortality may be expected to have occurred in river beds and beds in shallow and narrow estuaries in 1920, but it is considered that the actual amount of increase in mortality would be only a small portion of the excess of mortality estimated on oyster beds for 1920 : off-shore oyster beds, as at Whitstable, would be affected to a much less extent by weather conditions, and only slight mortality due to those conditions may be expected to have occurred there in 1920.

In 1921 the prolonged hot summer can certainly be connected with increased mortality (1) by the exposure of oysters on beds between tide marks to prolonged heating by the sun, and (2) by an extension of the spawning period of the oyster, and thereby increasing mortality associated with spawning. It is considered that many reports of unusual mortality in 1921 are accounted for satisfactorily in this way, and are generally of less importance than those issued in 1920.

(2) Oyster Pests.

No unusual pest was reported or found on oyster beds in the Thames Estuary in 1920 or 1921. The Blackwater beds had few burrs (*Echinus miliaris*) and starfishes (*Asterias rubens*) in 1920, and whelk-tingle (*Murex erinacea*) was stated to be not unusually abundant. No other pests were noted at the end of October, 1920. The beds off Whitstable showed large numbers of burrs and starfishes in November, 1920, and afterwards, but were apparently not more abundant than usual. On these beds it was found that in five months in 1921 in an experimental cage the mortality due to burrs was 3·2 per cent, or at the rate of 8 per cent per year, and that possibly—but not certainly—due to star-fishes 11·4 per cent in five months. It is pointed out that mortality due to these pests is certainly higher than has been realised, and further experiments are called for to determine it more accurately.

The mortality on the above-mentioned beds was, however, certainly due largely to other causes than the pests noted.

(3) Investigations for Parasites.

In the early period of the investigations sound and weak oysters and samples of sea water were examined in various ways for bacteria by Professor Eyre, but apart from the discovery of two undescribed organisms which were found by experiment to be harmless to oysters, little difference was found qualitatively between sound and weak or dying oysters, and no evidence could be obtained of any dangerous bacterial parasite. Professor Eyre's examinations were carried out mainly at relatively high temperatures, but fortunately a general infection experiment was carried out concurrently with the above examinations in the tanks at Plymouth at sea temperatures. In this experiment batches of so-called diseased oysters were kept in tanks in contact with sound oysters without causing any significant mortality over a period of more than a year. Cultures of oyster tissues in oyster broth was found to yield various organisms and fed to oysters at Plymouth with impunity: it is therefore regarded as highly improbable that any lethal infectious parasite was present in oysters after October, 1920. Careful examination of numerous freshly dead, weak and sound oysters, has led to no discovery of parasites which can be considered dangerous, nor has any dangerous parasite been found in the examination of microscopic sections of portions of fifty oysters. It is, nevertheless, impossible to state definitely that parasitism is not the cause of the unusual mortality observed, but it can be said that it is at least very doubtful that the mortality of oysters after October, 1920, has been due to parasites.

(4) Observations on "Hockley" and Sound Oysters.

A "hockley" oyster is one which sounds hollow when struck with a hard object, or is gaping slightly. The occurrence of hocklers is well known and slightly different terms are used to describe them in different parts of this country and elsewhere.

Oysters may become hockley from a variety of causes, temporary or permanent, and there is every reason to believe that all individuals which may be moribund from most or all the ills to which oysters are liable become hocklers eventually. Other bivalves may become hockley in the same way as oysters; thus one may speak of hockley clams.

The supposed diseased oysters of the Thames Estuary of the summer of 1920 and 1921 were hocklers which, however, were frequently well-fished individuals in good condition, and in other respects sound. Of 700 bona-fide hocklers—i.e. gaping for no obvious reason—transported from Whitstable to Plymouth tanks late in 1920, 10 per cent recovered even after making the railway journey in a more or less gaping condition.

From records kept for the writer by the Seasalter and Ham Oyster Co., Whitstable, it is clear that the occurrence of hocklers is seasonal, varying from a minimum of about 1 in 1000 or even 1 in 3000 in winter to about 1 in 100 at about July, as estimated from freshly dredged oysters examined within about twenty-four hours. At the end of October, 1920, the proportion was given as 1 in 400, and at once showed diminution.

Little is known of the pathology, physiology and even histology of the oyster. The parasites found in weak oysters were all regarded as secondary and attracted by the poor or dying condition of the oyster.

Various hitherto undescribed symptoms observed in weak or dying oysters, and at first thought to be abnormal, were afterwards found to be probably normal; such as degeneration of ova in the gonad; curious, highly vacuolated cells present only in the gonad of recently spawned oysters; protoplasmic processes on the sperm morulæ probably serving as channels of nourishment in development; and possibly also the phenomenon of diapedesis or bleeding; heavy concentrations of blood cells around the gut; the occurrence of cysts and excretory deposits on the shell and the occurrence of numerous gland-cells in the stomach and other parts.

In a few oysters were found large suppurations involving relatively large portions of the body—in two cases involving the whole of the stomach. Large suppurations have been recorded previously by Ryder and Giard. In 824 hockley oysters 3 per cent were found to have cysts or suppurations, but a similar percentage was found in 230 sound oysters examined. Excretory deposits on the shell were found in 14·9 per cent of hockley oysters of which 1272 were examined between February 9th and May 10th, 1921.

Some hocklers and some sound oysters also were found to show fatty degeneration of patches of the epithelium in the stomach and other parts of the gut.

The most constant symptom observed in hockley oysters is the occurrence of microscopic muscle spindles *throughout the tissues* of such oysters. These muscle spindles have so far as is known not been observed before in oysters; they vary in size from about $8 \times 2\mu$ to $90 \times 20\mu$, but were commonly from $20 \times 6\mu$ to $40 \times 10\mu$, while there is also much variation in width of spindles of the same length. They were observed first in an oyster on October 30th, 1920, but a considerable time elapsed before they were finally recognised as muscular in origin.

Spindles were frequently observed late in 1920, but their frequency was not determined. A sample of 53 fresh hocklers examined June 8th to July 20/21 for these muscle spindles, showed 60 per cent with few or abundant spindles, while samples amounting to 217 sound oysters,

examined June/August, 1921, showed 9·6 per cent with few or abundant spindles.

There is no doubt that the spindles are the product of muscular degeneration or myolysis, a phenomenon unknown elsewhere in Invertebrates until 1922 when De Horne described similar myolytic spindles in metamorphosing Polychætes. The source and cause of the formation of myolytic spindles in oysters has not been determined, but the adductor muscle is now strongly suspected as one source, but there may be other sources.

Spindles can be produced in oysters as artifacts, by bruising the tissues, while starvation also appears to tend to their formation, but poisons have so far failed to produce them in significant quantity; they have been met with sporadically in sound young oysters from the Plymouth as well as Mersea districts; in a hockler at Falmouth; in a culture experiment; in oysters starved in tanks at Plymouth; and in a few oysters from arsenic, T.N.T., and mercuric chloride experiments. In some of these oysters a few spindles only were found in the pericardium, but in others abundance occurred in the tissues. It is possible that myolytic spindles may occur normally in oysters, and Miss Worsnop has made the feasible suggestion that the spindles may be derived from the adductor and other muscles as migration occurs with growth of the shell by the assumption that one side of the muscle degenerates whilst the other is growing. It is pointed out that if this is the case then myolysis should occur generally in Lamellibranchs, and indications have already been obtained that this is probably true. Further research in this direction is required. It is insisted, however, that abundance of myolytic spindles in the tissues must be regarded for the present as pathological and requiring further research for an explanation.

Experiments on the period required for the liquifaction of the crystalline style when oysters are taken out of water are given, as also for the reformation of the style on replacing oysters in water. Slow liquefaction and quick reformation of the style occurs in oysters in good condition, while the reverse occurs on the whole in weaker oysters. In very weak oysters the style is absent. Absence of style or slow reformation of the style is correlated with a pale-coloured liver. A good oyster may not liquefy its style for from two to over ten hours after being taken out of water, and may reform it in three-quarters of an hour to two hours when replaced in water. A weak oyster may lose its style in three-quarters of an hour after being taken out of water, and take several hours to reform it when put back in water. The problem is, however, complicated by the previous treatment of the oysters. Much more work remains to be done on this subject, but useful results may be expected to follow.

Analyses of hocklers in late 1920 show a majority of them to have been

light-livered, but also a fair proportion with dark, healthy-looking livers. Other criteria of health are, therefore, required than good condition, dark liver and presence of style in oysters in water.

Bleeding or diapedesis has been observed in hocklers, but it was found that sound oysters after transportation or exposure to warm air in summer weather frequently bled copiously, and afterwards recovered. Large quantities of blood-cells leave the body, but it is not possible to see whether blood-fluid is always lost at the same time; apparently blood-fluid is only rarely lost, and no evidence has been obtained of rupture of the body wall: thus a true diapedesis is suspected. It is surmised, therefore, that the phenomenon may be purely a physical effect, namely, that certain conditions in the mantle cavity of the oyster induce the blood-cells to migrate from the body in few or even vast numbers. Diapedesis may, therefore, be a secondary symptom of hockley oysters.

The occurrence of myolysis, cyst-formation, and excretory deposits on the shells in hocklers, all suggest that there is a suspicion of a small proportion of oysters suffering from inflammatory causes of a nature so far undetected, but the readiness with which the tissues of the allies of the oyster are known to react to foreign bodies of no specially harmful nature render it doubtful that cyst-formation—for instance—is necessarily caused by poisonous substances. It is well known that non-toxic foreign bodies and parasites give rise to the formation of pearls in various bivalves.

Myolysis is probably the most serious symptom observed in hocklers, but further researches may be expected to explain the cause or causes.

The blood-cells of the oyster and also of some of its allies have been found to be able to live in ordinary sea water for three to four days outside the body of the oyster. This fact gave rise to suspicion at first of the presence of amœba-like parasites in the blood, but no such parasites have been found.

Oysters taken from the beds in October, 1921, and analysed for food-stuffs for comparison with unpublished analyses made by the Government chemist in conjunction with Dr. Wallace (Ministry of Agriculture and Fisheries) during the war showed that the October, 1921, oysters resembled the close season oysters of 1919, thus indicating that at the end of the extended summer of 1921 oysters resembled in condition spawning oysters of a normal summer. Researches carried out by the Public Health Department of the London County Council on the sea water of the Thames Estuary in connection with the disposal of rubbish, etc., indicate that the oxygen content, the salinity and temperature of the water on the line. Nore-Oaze-Black Deeps near the Edinburgh Light-vessel, on the site of the dumping ground were normal, or subnormal, in the year 1920. The salinity of the Thames Estuary water was high in the latter half of 1921,

but not higher than has previously been recorded by Dickson (1894). The oxygen requirements of the oyster and its allies are discussed, and it is shown that oysters can live for at least several days without an external supply of oxygen and recover, but further research is required to establish the minimum amount of oxygen which oysters can live in for extended periods, and the effects on oysters of water super-saturated with oxygen.

Oysters in various conditions—and other material—have been preserved at all stages of the investigations for the purpose of comparison in the eventuality of some malignant symptom being found in oysters in the future ; a list of the preserved material is given.

INVESTIGATIONS REGARDING POSSIBLE DIRECT POISONING BY DUMPED MUNITIONS.

Complete lists of munitions dumped by the Ministry of Munitions in the Thames Estuary and in other localities, down to the end of 1920, and extensive lists of cargoes lost at sea in vessels carrying munitions and other dangerous materials are given and discussed. Many cargoes still remain to be traced and their dangerous nature to oysters investigated. No cargo has been found, however, which can be definitely connected with oyster mortality in the Thames Estuary.

(1) T.N.T.

It is known that 1250 tons of T.N.T. were dumped in the Thames Estuary during the period 1919–20, and, therefore, special attention has been given to estimating the effect of the T.N.T. dumpings on oysters on the oyster beds in that locality, and a variety of experiments have been carried out to determine the effect of definite concentrations of T.N.T. on oysters and other marine animals and the rate of destruction of T.N.T. in sea water ; while in November, 1920, samples of water were collected from all parts of the Estuary and tested for the presence of T.N.T. and allied substances. Although much work has been done on the reactions of T.N.T. much more could have been done with profit but for the limitations of the money available.

Fourteen samples of water from the environs of the Thames Estuary (21 Oct.–29 Nov., 1920) were found to contain no T.N.T. with Brady's test which will detect one part of T.N.T. in fifty millions of water.

Control tests with T.N.T. in seawater, made in 1922, show that T.N.T. *in solution at the time of sampling* would not alter appreciably—if at all—in the time which elapsed between the taking of the samples and the time of examination.

Thirty-eight separate samples of particles caught in fine silk nets floating near the bottom in representative situations in the Thames

Estuary showed no T.N.T. present except possible traces in two cases (9th and 15th Nov.). Only three of these samples were treated to ensure preservation of any T.N.T. that might be present, but tests carried out later showed that grains of T.N.T. one-fiftieth of an inch in diameter remain practically unaltered in a week in samples of floating particles captured in a similar way and with similar organisms present, as in the case of the 1920 samples.

Thus it can be stated that no appreciable nor significant amount of T.N.T. was present in solution or as floating particles in representative situations in the Thames Estuary after November, 1920

The rate of solution and saturation of T.N.T. in sea water varies very slightly at temperatures almost within the limits of the variation in temperature of sea water in the Thames Estuary, namely, at 37° and 63° F.

T.N.T. dissolves very rapidly to saturation point in a small constant volume of seawater kept constantly agitated, attaining a saturation-point of 110 parts in a million in twenty-four hours at about 62·6 to 64·4° F., and 105 parts in a million at about 37° F., but it dissolves very slowly in the sea and in tanks; a lump of T.N.T. lost less than 3 per cent by weight after being in a tank with frequent stirring of water for seven months, while a piece of T.N.T., weighing about 3 to 3½ lb., kept in a cage in the sea, lost by solution probably less than 20 per cent in eight months, but certainly less than 30 per cent by solution and abrasion. A *greyish* deposit acquired by the T.N.T. in the tank certainly interfered with the solution, but the T.N.T. in the sea had the appearance of a clean fresh surface when hauled.

Samples of Berkefeldt-filtered sea water, made up to one part T.N.T. in four millions and one part in thirty-three millions, remained unaltered in this sterile water after twenty-six hours. Many samples of *ordinary* sea water, made up to the order of one part T.N.T. in five to thirty millions of water, were found to have lost approximately one half of the T.N.T. within about eighteen hours or less. Samples of ordinary sea water containing living larvæ of the rock-barnacle made up to one part T.N.T. in eight millions was found to have been reduced to one part T.N.T. in twenty millions on examination eighteen hours later; the larvæ were living: one part T.N.T. in five million did not affect the larvæ until after four days, while one part T.N.T. in ten million had no effect on the larvæ, so long as the larvæ could be kept alive (about six days).

Solutions of T.N.T. made up to estimated known strengths of the order of one part T.N.T. in thirty to seventy thousand of sea water are found to lose from 30 to 76 per cent of the T.N.T. in solution in periods of from eight to four months when kept in diffuse light or diffuse sunlight. In sunlight the loss of T.N.T. is just perceptible in nine days; the destruction of

T.N.T. in this case appears to depend largely, if not entirely, on the intensity of the light. Powdered T.N.T. is decomposed very rapidly in direct sunlight.

Thus T.N.T. in a made-up solution remains constant for a period of about nine days even in diffuse sunlight but is afterwards gradually decomposed. Solutions of T.N.T. *added* to sterile water give a dilute solution which remains unaltered for a period, but solutions of T.N.T. added to water containing organisms quickly lose a portion of the T.N.T. by inter-action with the organisms. The organisms present in an ordinary sea water sample are sufficient to reduce the strength of dilute solutions of T.N.T. by half in eighteen hours, but by more than half if small living organisms be added. T.N.T. in solution, therefore, reacts with organisms in sea water and afterwards reacts with the chemical constituents of sea water when exposed to light. The products of decomposition of T.N.T. in contact with sea water in the presence of light are either not at all toxic or only slightly toxic, but further research is required to obtain more information.

The products of the decomposition of T.N.T. in solutions of the order of one part in 130,000 had no effect on oysters in Tank 4 in the Millport Experiment during a period of three and a half months.

The readiness with which oysters succumb in solutions of T.N.T. depends upon the strength of the solution of T.N.T. and the time oysters are subjected to solutions. A saturated solution of T.N.T. (ca. 1 : 10,000) will kill oysters in two or three days.

Oysters in water in bell-jars to which lumps of T.N.T. are added succumb in from four to seven days.

In a tank containing about 600 litres of water and excess of powdered T.N.T. for saturation it took three weeks to kill thirty nine oysters.

In a similar tank containing a lump of T.N.T. about $\frac{1}{2}$ lb. in weight it took five months to kill forty two oysters.

In four tanks placed in series each containing about forty oysters and fed by freshly pumped water for sixteen weeks from a tank containing 10 lb. of crushed fresh T.N.T. no significant amount of death occurred in the last tank in the series, which is estimated to have contained T.N.T. in solution of the order of one part in five million.

In an experiment carried out in the sea less death of oysters was experienced in eight months in a cage containing 3 to $3\frac{1}{2}$ lb. of T.N.T. than in a similar cage in an adjacent situation without T.N.T.

On the wooden container of the T.N.T. in the sea a variety of different animals settled as larvæ and grew both on the inside and practically touching the T.N.T., and on the outside.

The loss of weight of the lump of T.N.T. in the sea experiment shows that only excessively dilute solutions of T.N.T. could have occurred even in the immediate vicinity of the T.N.T. Calculations of the possible

extent of solutions of T.N.T. in the sea can only be made on hypothetical conditions; on the most favourable hypothetical conditions for solution of T.N.T. in the Thames Estuary it would appear that this substance could never have attained a concentration likely to affect oysters on oyster beds in any way.

Oysters reject grains of T.N.T. forcibly injected into the mantle cavity and are known to reject noxious foreign particles. It is considered unreasonable in relation to the dumping of T.N.T. that any considerable quantity of grains of T.N.T. can have been present on oyster beds in 1920 and caused unusual mortality.

The conclusion is arrived at that unusual mortality of oysters was not due to T.N.T. in solution, nor to the ingestion by oysters of grains of T.N.T., but that it is possible that a small and negligible amount of death may have occurred by the latter means.

(2) Nitrites.

In January and May, 1921, the amount of nitrite, estimated as nitrogen, present in the water of the Thames Estuary in representative situations was found to be from 0·00020 to 0·00057 parts in 100,000 parts of water. These figures are normal for estuarine situations as is shown by results previously obtained by other workers and analyses of other samples from Plymouth Sound and Helford River, An experiment carried out in a tank at Plymout, in stagnant aerated water, containing at the beginning of the experiment 450 (four hundred and fifty) times the normal amount of nitrite, showed that even this high concentration of nitrites had no appreciable effect on oysters and many other marine animals during a period of eleven weeks. A sample of the experimental oysters kept in tanks for nine months after the experiment showed that no ill effects had resulted. The excess of nitrites in the experimental tank was gradually destroyed presumably by bacteria.

Nitrites are regarded, therefore, as not even a probable cause of mortality among oysters in the Thames Estuary in the summer of 1920.

Large variations of nitrites were found in Plymouth tanks confirming earlier unpublished researches by Matthews.

In the sea there is evidence that nitrite formation occurs largely in winter, but it is known also that nitrite formation from sewage takes place rapidly at relatively high temperatures in water poor in oxygen.

(3) Oil.

An experiment with oil taken from the sea at Whitstable and identified at the Government laboratory as *petroleum residue*—carried out in a small bell-jar showed that this substance has little effect on oysters; one oyster lived four months with repeated additions of the oily substance, and some

sea worms (Ophryotrocha) multiplied abundantly on the tarry scum and were eating it—possibly for the associated organisms. Analyses of the water made at the Government Laboratory at various stages of the experiment are given, and show that traces of oil and acidic bodies in solution derived from the oil were present in the water in solution, but in minute quantities which would be negligible in the sea from even a large quantity of oil.

Mitchell's work showing the relative harmlessness of water-gas tar on oysters is discussed, as is also Shelford's work on the toxicity of the constituents of fuel oils and coal tars and other work on the constituents of oils. Further work on marine animals on similar lines is recommended, especially with regard to acridine found by English workers—in connection with unpublished investigations on the effect of tarred road washings on fresh-water life—to be toxic in the proportion of one part in five million on fresh-water organisms. The conclusion is arrived at, however, that *apart from actual contact of oil with oysters*, oil in sea waters subjected to tidal movement may be expected to be harmless to oysters and the oyster planter.

(4) Copper, Zinc, and some other Metals than Arsenic.

It has long been known that copper is present in fair quantity in oysters from certain localities in the neighbourhood of copper deposits and pollutions, as at Mylor Bank, Falmouth, and various places in America, and gives rise to a condition which has been described as green leucocytosis (Herdman and Boyce). Zinc has also been found in large quantities in oysters from all parts of America (Hiltner and Wichman) and from some parts of England (Fishmonger's Co.). Moreover, traces of copper are known to be present in the blood of most Molluscs. The large amounts of various munitions and metals thrown into and lost at sea rendered it desirable to test oysters for as many metals as possible. Mylor Bank oysters, which are known to fatten and breed and to be otherwise apparently healthy, were analysed for metals to obtain a criterion of what oysters could withstand; they were found to contain

Copper in the proportion of 290 to 3300 parts per million of oyster meat
Zinc ,, ,, 70 to 2100 ,, ,, ,, ,,
Tin ,, ,, 40 to 220 ,, ,, ,, ,,
but the latter metal may be absent.

Apparently healthy Pecten from the Mylor Bank and the neighbouring locality were found to have

Copper in proportion of 10 to 690 parts per million of oyster meat
Zinc ,, ,, 210 to 300 ,, ,, ,,
Tin ,, ,, 0 to 20 ,, ,, ,,

Oysters from the Thames Estuary and other beds contain nothing like this proportion of metals, and since no large quantity of them has been known to have been lost at sea near oyster beds it is concluded that copper and zinc have played no part in the reported mortality of oysters.

The normal amount of metals present in sound, edible, English oysters is from 30 to 90 parts of copper and 280 to 480 parts of zinc with upwards to 40 parts of tin and upwards to 90 parts of iron per million parts of oyster meat: in good eating oysters of an average weight of 10 grams there would be respectively approximately $\frac{1}{200}$th to $\frac{1}{70}$th grain of copper, approximately $\frac{1}{25}$th to $\frac{1}{15}$th grain of zinc, upwards to $\frac{1}{70}$th grain of iron and in some cases upwards to $\frac{1}{180}$th grain of tin, and as has been shown, probably also traces of arsenic.

It seems probable that the medicinal properties of oysters may depend upon these facts.

Copper and zinc are now known to be almost universally present in marine animals, even in situations where these metals cannot be detected in sea water.

There is no uniformity in the proportions of metals present in oysters.

Mercury, Barium and Lead have been tested for and found to be either definitely absent, or no evidence has been obtainable of their occurrence in analyses of oysters, soils, and tow-nettings, and are eliminated as causes of mortality. Aluminium is considered, and also not regarded as a likely cause of mortality.

Radio-active elements and antimony have not been tested for in oysters and soils, but no special reason has arisen to suspect these elements. Herdman and Boyce have shown that the blood-cells of the oyster contain much copper, but chemical analyses of blood-cells made at the Government Laboratory, and other facts indicate that most—if not all—of the metals in oysters are concentrated in the blood-cells.

An analysis of blood-cells taken from Mylor Bank oysters gave, in one million parts, approximately 5180 parts of copper, 8130 parts of zinc, 490 parts of tin and a trace of arsenic.

Other analyses show that the blood-cells contain far more metals than the oysters analysed as a whole, and particular oysters may contain a far greater proportion of metals than has been obtained from analyses of samples of soil taken at the same time as the oysters.

Oysters, therefore, accummulate metals from the surrounding medium, but also as is well known can clear themselves of metals to a great extent on being transplanted to a medium poor in metals. There is good reason to believe that this phenomenon is common to many Lamellibranchs. Thus it is clear that the blood-cells of the oyster—and other Lamellibranchs—are primarily concerned in the segregation and excretion of

metals. It seems possible that metals are excreted by the blood-cells leaving the body of the oyster and carrying the metals with them.

(5) Arsenic in Oysters and Soils.

The absence of poisonous substances in solution in the sea water of the Thames Estuary led to a search for insoluble poisonous substances of which arsenic was one. Arsenic was found in oysters from the Thames Estuary in larger proportion than is allowed in food, both in sound oysters and supposed diseased oysters, but it was known that arsenic had been reported in American oysters (Wichmann) in small proportion, so that a more extensive examination of oysters, soils and other animals for arsenic was required to determine the relation of the presence of arsenic in oysters to the question of mortality.

The whole of the analyses for arsenic and other metals in oysters, soils, sea water and tow-nettings has been carried out by the staff of the Government Laboratory. Arsenic has now been found in sound and weak oysters from all localities where samples have been obtained for analysis Oysters have been been analysed whole, but the contents of the alimentary canal are smaller in amount on the average in the weaker oysters. The proportion of arsenic in weak oysters is, on the whole, greater—but not on the whole markedly greater—than in sound oysters, and varies from a trace—or none at all— in sound oysters to as much as five parts in a million of fresh oyster meat. In April, 1922, samples of sound and weak oysters taken at the same time from the oyster beds at Whitstable gave on analysis no arsenic in the sound oysters, but proportions of three and six parts in a million in the weak oysters ; the whole of the analyses of oysters indicate a tendency to the accummulation of arsenic in the weaker oysters. The amount of arsenic found in sound oysters from the Mylor Bank beds—where arsenic occurs in the soil in great abundance, as has been shown by analyses—has been found to vary from nothing to as much as five parts in a million. The absence of arsenic in some of the oysters from these beds and the almost constant presence of arsenic in oysters from the Thames Estuary rendered it necessary to treat the problem carefully.

No pre-war analyses for arsenic of oysters, soils, sea water or tow-nettings from the Thames Estuary are known, or believed, to have been made.

The amount of arsenic present in soils on the oyster beds and main channels in the Thames Estuary, in the sea water, and in tow-nettings of particles floating near the bottom has been determined and found to vary from twelve to sixty eight parts in a million of dried soil from the Oaze Deep (after removing the coarser particles), and smaller proportions from the oyster beds themselves, and from tow-nettings of floating particles.

The amounts found are considered large and suspicious, and cannot yet be satisfactorily accounted for; it would appear that innocuous or on the other hand, dangerous commercial effluents or unknown dumpings containing arsenic may be the source.

It is possible, therefore, that the arsenic found in the Thames Estuary is in a different—and may possibly have occurred originally in a dangerous state—from that in the locality of Mylor Bank. No proof of any recent loss of arsenic in significant amount in the Thames Estuary has been obtained, but if it can be shown that arsenic in a dangerous state of combination has passed into the waters of the Thames Estuary prior to the summer of 1920, it will be necessary to carry out fresh investigations regarding arsenic and to review the whole of the data obtained in that light.

The blood-cells of oysters from Mylor Bank gave only a trace of arsenic on analysis, and the hearts of fifty weak oysters from Whitstable only two parts of arsenic in a milliom. The gut contents of oysters and blood-cells of weak oysters from the Thames area have not been analysed separately.

Arsenic and other metals have been estimated in silts from various localities: the proportion of arsenic found in the dried silt in parts per million at Mylor Bank was 835 to 1600, at St. Just Pool, 100 to 225, at Plymouth, in a few fathoms north of Drake's Island, 14 to 27, Helford River, 13, Blackwater River, 3 to 22, near mouth of Colne River, 5 to 17, off Whitstabel, 2 to 22.

Other animals than oysters have been analysed for arsenic; *Pecten varius* from Mylor Bank were found to contain 2·5 parts of arsenic per million, whilst similar specimens from St. Just Pool, taken on the same day, contained no arsenic; the sponge, *Ficulina ficus*, G.W. Docks, Plymouth, contained five parts per million, and *Hymeniacidon sanguineum* from the same locality contained three parts of arsenic per million on the wet weight. Similar amounts were found in the latter sponge from Falmouth.

Arsenic in sea water from the Blackwater River was found in the proportion of about three parts per hundred million, and a similar proportion in sea water from the Ham Grounds off Whitstable, and 2·5 parts per hundred million in water from the mouth of the English Channel.

Arsenic was found in tow-nettings consisting of floating particles and small living organisms, in proportions varying from a trace to thirty one parts per million (air-dried) in the Thames Estuary and a trace to seventeen parts per million (air-dried) in the Newton River, Isle of Wight. Further analyses of collections of the minute organisms alone are required to evaluate the results of analyses of tow-nettings containing both organisms and floating particles. Arsenic in traces, that is, of the order of

one part in ten million has been found in the carapace of the crayfish, and smaller amounts still in the carapace of prawns and shrimps, (Gautier and Clausmann). The total evidence, however, indicates that the arsenic found in tow-nettings is present mainly in particles, and not in combination with organic substances derived from living organisms. The analyses of tow-nettings, therefore, show how the oysters in the Thames Estuary are obtaining their arsenic.

Iron pyrites from the Thames Estuary has been found to contain only traces of arsenic, namely, 0·01 per cent. and no arsenic was found in flints. Thus it would appear that local minerals will not account for the arsenic in the Thames Estuary, and, indeed, the accumulation found in the Oaze Deep suggests a recent source, not entirely accounted for by the apparently small amount of arsenic contained in thirty tons of arsenic refuse, dumped, however, in September, 1920.

Sound oysters yielding the maximum amount of arsenic found, namely, five parts of arsenic in one million parts of oyster meat contain about three and a half times more arsenic than is allowed in food (1/100 grain in a lb.). It would, however, be necessary to eat more than two dozen of such oysters to take the minimum daily dose given in the British Pharmacopœia. It has been pointed out by the Government Chemist that it would be necessary to consume 57 (fifty-seven) dozen oysters such as were present on the oyster-beds in August, 1921, (i.e., containing an average of 3·6 parts of arsenic per million and of an average weight of 8 grams) to take such a daily dose of arsenic as is allowed by the German Pharmacopœia.

As no pre-war analyses of English oysters (*O. edulis*) for arsenic are known, there is no evidence that these oysters did not contain similar amounts of arsenic then as now, and there is reason to believe that all oysters at some time may contain arsenic, and that in that case their edibility may be no different, or little different now, from formerly(*Vide* analyses of Lachryan oysters). There is no doubt that sound oysters have remained edible—as regards arsenic content or otherwise—during the course of these investigations. It is recommended, however, that periodical analyses of oysters should be made by the Government Chemist until the amount of arsenic in oysters is satisfactorily accounted for.

Oysters can be kept in sea water in bell-jars containing white arsenic for many months without harm; such oysters have been found by analysis to contain as much as twenty one parts of arsenic as As_4O_6 in a million, Under these conditions oysters apparently easily absorb and easily lose the absorbed arsenic. Oysters in arsenicated sea water give off continuously for months an arsenicated gas resembling—and probably identical with—arsine; thus the living oysters react in some way at present unknown with arsenic. The amounts of arsenicated gas produced

daily are minute, but recognisable easily by the strong characteristic odour. The experiment with controls is easily performed. The possibility of using oysters as a test for arsenic, as As_2O_3, is suggested.

The mode of absorption and retention of arsenic in oysters is not known, and there are indications that arsenic is held differently in oysters from copper and zinc.

The amount of arsenic in oysters, it is pointed out, is relatively very small compared with that of copper which can be held with impunity, reaching a ratio as high as 1 to 660 for the maximum amount of arsenic and 1 to 1300 for about the average amount.

Instances are given of substances accumulated in abundance in animals from sea water containing only traces of those substances. Arsenic as well as copper, zinc, barium and iron, has been shown to be present in sea water in traces

An arsenicated paint which was just losing its toxicity to *Obelia sp.*, probably *O. geniculata*, after three and a half years immersion in the sea was found to contain 0·4 per cent. of arsenic as As_4O_6.

Thus until more information is available as to the condition now, and formerly, of the arsenic found in the Thames Estuary, and of the reactions of oysters to arsenic compounds, it is not possible to connect the occurrence of arsenic in oysters with an unusual mortality of oysters, and it may well be that all oysters may at some time contain arsenic in approximately the amounts here recorded.

(6) Sodium Picrate.

Experiments carried out with picric acid on oysters—and unpublished experiments carried out by Allen and Lebour with sodium picrate for the Ministry of Agriculture and Fisheries—show that these substances are only slightly toxic in sea water, and that toxic solutions would give a distinctive colour to the water. The dumpings of this material are considered, and the conclusion arrived at that sodium picrate can be eliminated as a likely cause of death of oysters in 1920.

B. ISLE OF WIGHT AND SWANSEA AREAS.

The mortality among oysters in the Isle of Wight area differs from all others in being reported in the winter of 1920-21, but as the mortality was reported to have ceased in January, 1921, a large portion of the mortality may have occurred undetected in the summer of 1920. No cause of the mortality was detected in the investigations carried out, but information regarding dangerous cargoes of munitions lost in the vicinity during the war renders further enquiries necessary to estimate the possible

effect of the lost munitions on oysters. The information mentioned was received only recently, and too late for the writer to prosecute further enquiries.

It is noteworthy that some oysters from the Isle of Wight area contained relatively large amounts of arsenic, although copper and zinc were absent.

Little information was obtained from Swansea, other than the reports of unusual mortality of oysters, but indications were obtained from inspections of the beds that other animals on the oyster beds and in the vicinity had been healthy in the preceding summer. The mortality appeared to have ceased after the receipt of the reports and no cause of the reported mortality has been found.

Experiments on Oysters.

It is known that oysters may acquire a weakness which may not be shown until after the lapse of a considerable period, and that the summer time is a critical one for all oysters. In experiments on oysters it is essential to bear these facts in mind. Moreover, oysters will vary in condition at the same time of the year in different localities, so that locality, actual date of transport, and conditions of transport, as well as the time of the year transported, and the length of time oysters have been relaid, whether on the beds or in tanks, have all to be taken into consideration in beginning an experiment. To complete observations on oysters which have been experimented upon, it is advisable to record the conditions of oysters over a considerable period—in months—after the conclusion of the experimental conditions. As oysters will usually live in tanks during the winter with a low mortality rate, even when not in very good condition, the winter period is a very good one for differentiating mortality due to experimental conditions. The complex conditions of oysters render it advisable always to carry out exact control experiments even if the tank space available be small, and the number of experiments to be carried out simultaneously be thereby reduced.

The ideal experiment on oysters is carried out in the sea ; the nearest approach to this condition is to subject oysters to experimental conditions in the laboratory and afterwards transplant the oysters in isolation in the sea.

CONCLUSION.

The lack of reliable information regarding normal mortality in native and relaid oysters has needed to be borne in mind during the whole course of the investigations, and it is regarded as probable that the normal mortality may be much higher than is realised or acknowledged by oyster-

cultivators. It may be said that the oyster is a domesticated animal, and as such may be subjected to treatment resulting at times in grave constitutional disorders, and consequently in a high rate of mortality. It is the residual mortality derived from deducting the normal from the total of the unusual that has to be accounted for. It is considered possible that a fraction of this residual mortality may be accounted for by abnormal weather in shallow water and river beds, and by pests on the beds off Whitstable, but it is further considered unlikely that these increments would account for the whole residual mortality estimated by the oyster planters, who are the only bodies in a position to make approximately reliable estimates.

It seems possible that whatever is causing the inflammatory conditions observed in oysters, may account for a further fraction of the residual mortality, but, on the other hand, these inflammatory appearances may be of normal occurrence and may need to be included in the normal causes which lead to death.

It has been shown that T.N.T. could not have been the cause of unusual mortality, and that it is highly probable that arsenic is not a cause of unusual mortality, and that no evidence nor knowledge of the presence in oysters or sea water of any other poisonous substance which is a probable cause of abnormal mortality has been obtained. It is shown, however, that a knowledge of the materials which may have passed into the Thames Estuary is incomplete.

Thus no poison has been found to explain an unusual mortality. At the same time no parasite has been found to explain unusual mortality, and although it is impossible to say that oysters have not been dying owing to parasitic attacks, it is considered extremely unlikely that any dangerous parasite of an infectious nature was present in oysters after November, 1920.

Of the oysters dying from no apparent cause it has been shown that a good proportion contained abundance of myolytic spindles in their tissues. Myolysis has not previously been described in oysters, and although the phenomenon is regarded as probably normal, yet it is considered that the condition of excessive myolysis is pathological.

The failure to find a satisfactory cause of the unusual mortality in either weather effects, poisons, parasites, or pests may be due to absence of information or failure to recognise some feature or fact under either of these branches of the work, or, on the other hand, may be due to (1) the possibility that the cause of the unusual mortality in 1920 disappeared by the time the investigations were undertaken—when the mortality was said to be over—or (2) that oyster planters may in good faith have overestimated the mortality in 1920—although this seems improbable in many cases—and that the mortality in 1921 was what might be expected.

It is shown however, that no single cause or group of causes has been found singly or collectively to account for a heavy and unusual mortality of oysters in the Thames Estuary in the summer of 1920, but it would appear that the discovery of the cause of excessive myolysis—a condition heretofore undescribed in oysters—observed in hockley oysters in good condition, might lead to a satisfactory explanation of that portion of the mortality which cannot be included in the normal.

On the Physiology of Amœboid Movement. I.

By

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With Figures 1–10.

Of the relation of amœboid movement to other forms of contractility, very little is known at present. Hypotheses have been advanced to explain the movement, but they differ widely among themselves, and are founded almost entirely on direct observations of the normal activities of amœba. More recently Loeb (**24**) (**25**) and others have tried to determine the *rôle* of various environmental factors, such as the presence of certain salts, in amœboid activity. It is on these lines that the present work is being conducted.

Material, Methods, etc.

Marine amœbæ were used in the experiments, since sea-water as a medium has advantages over fresh-water for the following reasons :—

(1) The osmotic pressure of sea-water can be increased or reduced with ease, but it is almost impossible to determine the effects of hypotonic solutions on fresh-water organisms (compare Greely, **14**).

(2) Solutions can be prepared which are isotonic with sea-water, but which have certain ions in excess or deficit.

(3) The hydrogen ion concentration can be kept more constant.

(4) Marine amœbæ usually, if not invariably, possess no contractile vacuole : their physiology is therefore probably simpler than that of fresh-water amœbæ.

The material was obtained from an open tank, 4 ft. by 2½ ft., which was fed by a slow stream of sea-water almost continuously. The supply of sea-water was pumped from the Laboratory storage tanks. This water, which will be referred to as " tank water," contains more phosphates and more organic matter than does water from the open sea. An account of this " tank water " has been given by Allen and Nelson (**1**).

The hydrogen ion concentration of the water in the open tank varied from pH7·8 to pH8·0; these values are higher than that of the "tank water" supplied, probably owing to the presence of an abundant growth of diatoms and filamentous algæ.

The water used in the following experiments for cultures, solutions, and so on, was open-sea-water, hereafter referred to as "outside sea-water."

The bottom of the tank was covered with a film of brown algæ, associated with diatoms and enormous numbers of a small brown flagellate (Chilomonas). A few ciliates of very diverse forms were present, and there were about half a dozen species of Amœba, readily distinguished by the character of their granules, the nature of their pseudopodia, and the average size.

The amœbæ used in the experiments were usually of the "limax" type. This type has the great advantage for experimental work that locomotion takes place by the formation of a simple pseudopodium, which, continuously pushing forward, is followed by the rest of the amœba. Three different species were used, but so little is known of marine amœbæ that as yet it has not been possible to identify them with certainty. They will, therefore, be referred to as "Type A," "Type B," and "Type C."

Type A (*Fig.* 1, *No.* 1 *and* 2).

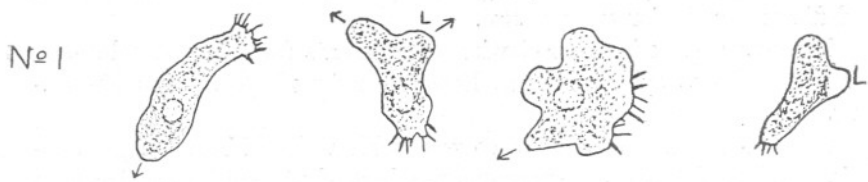
This amœba was usually of the limax form, varying in length from 50μ to 120μ, the average size being about 80μ long by 30μ wide. A large clear spherical nucleus was present. The advancing pseudopodium was large and rounded. At the hind end was a rugose tail-piece, which with careful observation could be seen to bear a number of fine clear processes, very different from the anterior advancing pseudopodium (Fig. 1, No. 2). These processes were capable of slow bending movements and of extension and retraction.

Although typically a limax form, this amœba often threw out a lateral pseudopodium (Fig. 1, No. 1). If this changed the direction of motion of the amœba, a fresh tail-piece developed at the new hinder end: the old tail-piece was either resorbed or else moved slowly towards the new hind end and ultimately fused with the new tail-piece (Fig. 1, No. 2). On stimulation the amœba often went into a temporary "proteus" condition with several pseudopodia, a tail-piece forming at the hinder end when locomotion commenced.

The entire mass of both endoplasm and ectoplasm usually consisted of translucent, but not transparent, protoplasm. A few fairly small granules were present in the endoplasm. The appearance suggested that the protoplasm was packed full of almost ultramicroscopic particles,

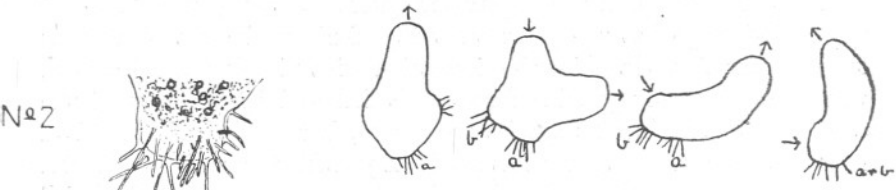
FIGURE 1.

TYPE A.



Limax. Limax-proteus. Note lateral pseudopodium (L). Proteus. Formation of a hyaline pseudopodium (L).

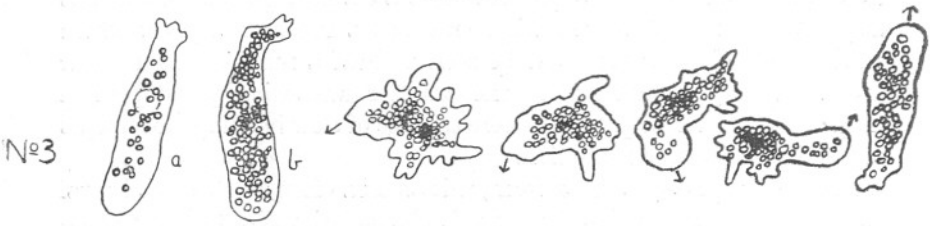
TYPE A.



Tail-piece enlarged.

Four successive positions of an individual amœba, to show formation of a new tail-piece (b) when the direction of motion is changed. Note migration of old tail-piece to new hind end.

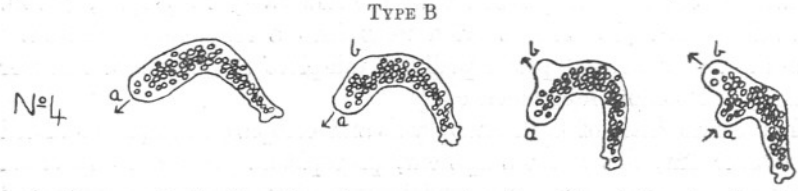
TYPE B.



(a) Specimen from tank.
(b) Specimen from culture.

Five successive stages showing the assumption of the limax from the proteus form.

TYPE B



Four successive stages in the formation of a new pseudopodium (b), and the retraction of the old one (a). Note that the granules seem to be pushed inwards by the swelling ectoplasm.

a condition also indicated by the brilliance with which the entire amœba shone under dark-ground illumination. The thin ectoplasm differed from the endoplasm in the relative absence of the small granules. If any of these were present they seemed to be temporarily fixed, and took no part in the irregular streaming movements of those in the endoplasm. However, occasionally a new pseudopodium had a cap of hyaline ectoplasm, like that of the fine pseudopodia of the tail-piece (Fig. 1, No. 1).

The protoplasm seemed to be very fluid. If an amœba were sucked up with a fine pipette it adhered to the substratum by the tail-piece. The body of the amœba formed a round droplet attached to the tail-piece by a neck as though the fluid protoplasm were contained within a weak surface membrane.

These amœbæ resembled, and may have been identical with, those described by Lebour (**22**) from the plankton of the Plymouth region (Form " C," p. 157). They also bore a resemblance to the amœbæ described by Orton (**27**) as occurring in the gastral cavity of Sycon and elsewhere.

Type B (*Fig.* 1, *No.* 3).

This amœba was a typical limax form, moving for relatively great distances without forming lateral pseudopodia. The animal was long and thin, varying in length from 70μ to 150μ, and in breadth from 20μ to 35μ. The tail-piece was rugose, but bore no fine pseudopodia. A " proteus " form was developed on stimulation, the pseudopodia of which were at first composed entirely of ectoplasm, while the endoplasmic granules were concentrated in a central mass (Fig. 1, No. 3). Later the granules flowed into one of the pseudopodia, which, increasing in size, became the advancing main pseudopodium of the amœba. The other pseudopodia now rapidly diminished to form the rugose tail-piece of the normal amœba.

The protoplasm was hyaline and highly refracting. There were large dark granules in the endoplasm. These were few in number in amœbæ taken from the tank, but in those obtained from cultures the number increased with the age of the culture till the protoplasm was densely packed (compare Fig. 1, No. 3, a and b).

During locomotion some granules became embedded in the ectoplasm : these, as in Type A, were relatively fixed in position, unlike the streaming granules in the endoplasm. The anterior end of the advancing pseudopodium was often free from granules, those of the endoplasmic stream being unable to penetrate it. A new pseudopodium formed at the side of the amœba at first consisted entirely of granule-free ectoplasm, and it was often observed that endoplasmic granules immediately below the pseudopodium were actually pushed inwards as the pseudopodium swelled (Fig. 1, No. 4).

The amœbæ were of a stiffer consistency than Type A. When sucked into a pipette they retained their shape and could be set down elsewhere without great change of form, though ultimately the mechanical stimulation caused them to take on the proteus form.

So far this amœba has not been identified with a described species.

Type C.

This amœba resembled Type A, except that there was a much greater tendency to assume the proteus form. The size ranged from 70μ to 150μ in length, by 40μ to 80μ in breadth. The protoplasm had a faint yellow tinge, and was more granular than in Type A: vacuoles were sometimes present. The protoplasm was rather less fluid than Type A. Fine processes were present on the tail-piece as in Type A.

This amœba also has not yet been identified.

Cultivation.

All three types of amœbæ can be grown in culture, though Type A cultures tend to become infested with ciliates (Euplotes and others). The cultures were prepared by a modification of Taylor's method for fresh-water amœbæ (**34**). A litre of "outside sea-water" and some Petri dishes were heated to 80° C. for half an hour, in order to kill the ciliates; once ciliates obtained a footing in a culture they multiplied rapidly, and the amœbæ fell off in numbers and disappeared. Wheat grains were now crushed and boiled in water till they were swollen. About twelve wheat grains were put in a Petri dish with 50 c.c. of sterile sea-water. A few drops of tank water were now added to the dish to infect it with bacteria, the water being drawn up slowly with a clean capillary pipette while under the microscope, to ensure that no ciliates were taken up.

In about a week's time a thin bacterial scum had formed over the bottom of the dish, and the remaining wheat grains were removed. Amœbæ from the outside tank or from previous cultures were now removed individually into clean sea-water by means of a fine pipette. This was done under the microscope. Three or four of these amœbæ were then retransferred to each culture dish. At the end of ten days most of the cultures contained large numbers of amœbæ. The cultures lasted for about two months, though one lasted over four (Type B). Sooner or later Type C amœbæ appeared in large quantities in these cultures, though no special precautions were taken to ensure their presence. In this way an abundant supply of Type C amœbæ could always be obtained from old cultures.

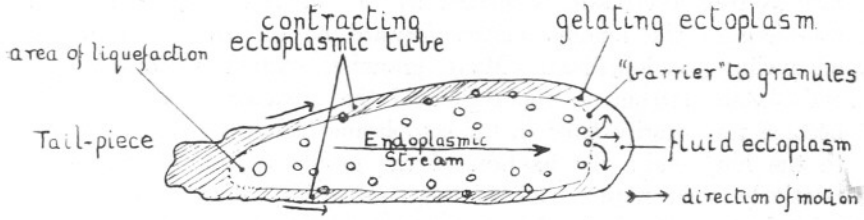
(1) THE LIMAX FORM OF LOCOMOTION.

This form of locomotion can be readily studied in Type B amœbæ, with their clear ectoplasm and large granules.

It has already been pointed out that we may look upon limax forms as amœbæ which obtrude a single persistent pseudopodium which is

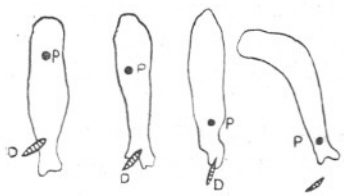
FIGURE 2.

No. 1.

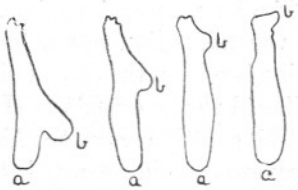


Diagrammatic illustration of the movement of a Type B amœba.

No. 2.



Four successive drawings of a Type B amœba to show migration of particles (P and D) to the tail-piece.



Four successive drawings of a Type B amœba to show the migration of a retracting pseudopodium (b) to the tail-piece.

No. 3.

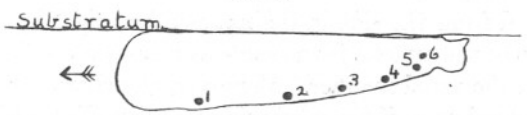


Diagram founded on observations of successive positions of a single large granule embedded in the ectoplasm of a Type B amœba (seen from side).

advancing continuously. In Type B amœbæ the endoplasm and its included granules stream towards the advancing pseudopodium (Fig. 2, No. 1). The head of the pseudopodium consists of a greater or less amount of clear fluid ectoplasm ; and it is important to note that endoplasmic granules are usually checked in their forward flow just behind this clear area, as though there were a weak barrier to the entrance of the granules into the anterior region of the ectoplasm (Fig. 2, No. 1).

The ectoplasm at the sides of the clear anterior region seems to become more solid. Since the ectoplasm in the middle and that which is anterior is advancing continuously, this solidification at the sides results in the formation of a tube of gelated ectoplasm. As the advancing pseudopodium continuously adds fresh solid ectoplasm, each portion of this tube, once formed, moves further and further back towards the hind end of the amœba.

The tube of gelated ectoplasm contracts continuously, the contraction increasing as the hind end is approached ; the hind end is contracting as fast as fresh ectoplasm is formed at the anterior end, so that the tail-piece of the amœba moves forward at the same rate as the advancing pseudopodium. Many granules, carried forward by the endoplasmic stream to the region of the advancing pseudopodium, become temporarily fixed in the ectoplasmic tube as this passes back to the hind end : the fixation of the granules attests both to the relatively solid nature and to the contractility of the ectoplasmic tube, because the increasing contraction of the tube as the hind end is approached is shown by the successive positions of individual granules (Fig. 2, No. 3).

If a lateral pseudopodium is formed and then retracted, it passes back to the tail region just as do the granules in the ectoplasm. The same thing is seen in the case of diatoms, lamp-black particles, etc., which have adhered to the ectoplasm (Fig. 2, No. 2).

The greatly contracted hind end of the ectoplasm tube, together with remnants of old retracted pseudopodia, forms the highly gelated rugose tail-piece (Fig. 1, No. 2).

Within the hind end of the amœba, in front of the gelated tail-piece, is a place of liquefaction : here, as Schæffer (**32**) has pointed out, the endoplasmic stream begins.

When viewed from the side in the manner described by Dellinger (**9**), the movement of the amœba is the same as it appears to be when viewed from above in the usual manner. Moreover, the character of the movement is unchanged even if the advancing pseudopodium is lifted clear of the substratum, or if the amœba is in contact both with the substratum and with a surface at right angles to it.

A forward rolling movement of the upper anterior surface of the amœba, as described by Jennings (**20**), was in no case observed ; nor did my observations on these limax amœbæ agree with the contractile network theory of Dellinger (**9**). The character of the movement is essentially the same as described by Rhumbler (**30**) : there is an "ento-ectoplasmic process," and the streaming does resemble a "fountain current," but there is no backward *current* at the surface, because the ectoplasm is not fluid ; it is the continuous contraction of the gelated

ectoplasm and its continuous formation at the anterior end which causes the outer surface to pass towards the tail-piece.

We can, therefore, conceive of the amœba as a contracting tube of gelated ectoplasm closed at its hind end. The endoplasm streams forward through this tube from a place of liquefaction within the hind end, and apparently forms ectoplasm at the anterior end. This anterior ectoplasm adds to the contracting tube by becoming gelated at the sides of the advancing pseudopodium.

(2) THE EFFECT OF OSMOTIC PRESSURE: THE WATER-CONTENT OF THE CELL.

The experiments were performed mainly on Type A amœbæ, though observations on Type B were used to check the results.

Hypotonic solutions of sea-water were made by mixing distilled water and "outside sea-water" in known proportions. For the hypertonic solutions a stock solution of 100·5 gms. of Tidman's sea salt in a litre of distilled water was made, the pH being adjusted by the addition of sodium carbonate to pH8·1, the usual pH of "outside sea-water." This solution has approximately three times the salt content of the "outside sea-water." Hypertonic solutions of various strengths were made by adding this solution to outside sea-water.

The effect of the "three-times-strength sea-water" solution was checked by dilution to three times its volume, when amœbæ were found to behave in it as they did in normal sea-water.

Hypotonic Solutions: Type A.

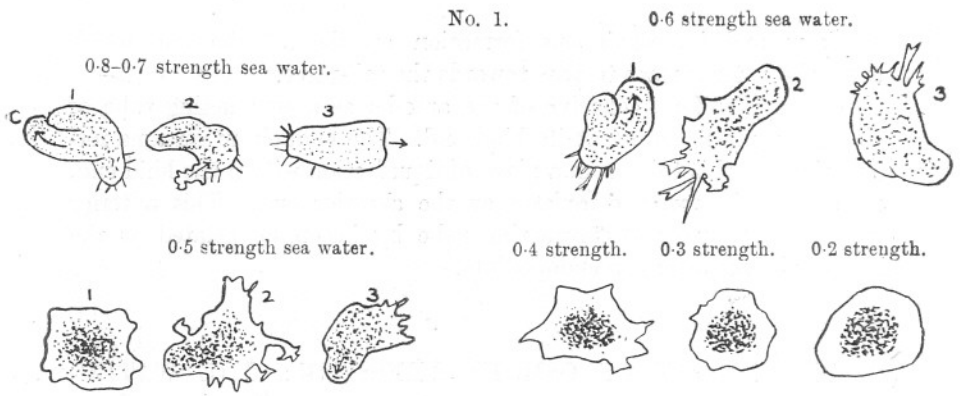
In hypotonic solutions the amœba absorbs water. Sometimes the activity of the amœba is slightly increased at first. The protoplasm becomes rather more fluid in hypotonic than in "outside sea-water," and this fluidity is often accompanied by the eruption of pseudopodia, which flow round the body in the manner described as a "circus movement" by Loeb (**25**) in the amœbocytes of Limulus (Fig. 3, No. 1).

If the osmotic pressure of the medium is lowered by stages the amœbæ are capable of considerable adjustment to the conditions.

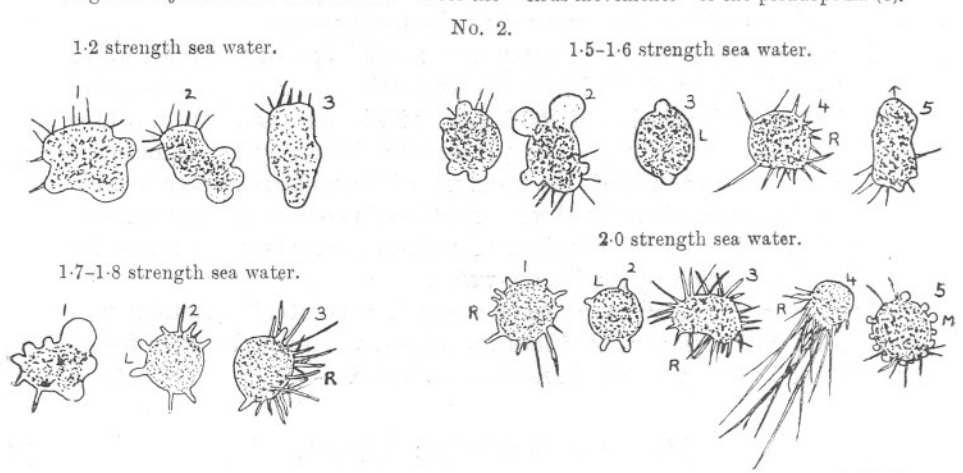
Figure 3, No. 1, shows drawings of changes in shape of individual amœbæ when the osmotic pressure was lowered in successive stages.

In "outside sea-water" the amœbæ were either in the limax, or in the "limax-proteus" form with a tendency to throw out new pseudopodia (Fig. 1, No. 1). When the medium was changed for 0·8–0·7 strength sea-water the amœbæ swelled slightly, and at first approached more

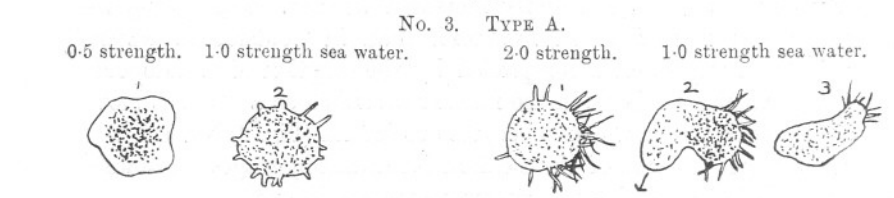
FIGURE 3.



Changes of form in Type A amœbæ in hypotonic solutions. The numbers 1, 2, 3 indicate successive stages in adjustment to the medium. Note the "cirus movements" of the pseudopodia (c).

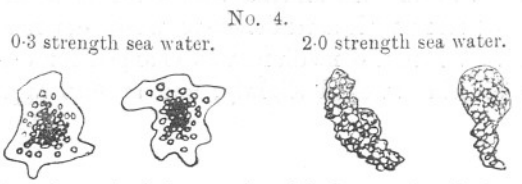


Changes of form in Type A amœbæ in hypertonic solutions. Note the "lemon" and allied forms (L), the "radiosa" forms (R), and the "morulate" form (M).



To show assumption of the radiosa form on transference from hypotonic to sea water of natural strength.

To show direct passage of radiosa pseudopodia into "fine processes" of the tail-piece on transference from hypertonic to sea water of natural strength.



Type B amœbæ in hypotonic and in hypertonic solutions.

nearly to the proteus form. The tail-piece increased in extent, and its fine processes became slightly larger. Pseudopodia, once put out, sometimes retracted with some difficulty, irregular projections appearing over them. These projections were finally absorbed into the tail-piece, and appeared to change into fine processes like the others covering this region. After a short time recovery took place and reversion to the normal type occurred.

If the solution was now changed to 0·6 strength sea-water the amœba again swelled. At first its form might be normal, but soon broad, rounded pseudopodia appeared, composed largely of clear ectoplasm: at the same time the fine processes of the hind end became broader and began to take on an appearance similar to the pseudopodia. At this stage the "fine processes" and the pseudopodia were somewhat flattened and adhered to the substratum. Recovery began after five or ten minutes, and ultimately a fairly typical limax form might be attained, but the movement was slower than in "outside sea-water."

On changing the solution to 0·5–0·4 strength sea-water the amœba again swelled. The ectoplasm formed a clear border round a central granular mass. Both the "fine processes" and the pseudopodia became similar broad sheet-like extensions of the ectoplasm, firmly attached to the substratum. These sheet pseudopodia underwent changes of shape, but the animal seemed incapable of locomotion. Later, as the amœba adjusted itself to the medium, the granular endoplasm began to penetrate the clear ectoplasmic region. The sheet pseudopodia thickened and became differentiated into broader rounded pseudopodia and finer ones. Ultimately the broader pseudopodia became fairly typical, while the finer ones congregated at the hind end as the "fine processes" of the tail-piece. However, the "fine processes" were still abnormally large and might even be represented by blunt pseudopodia.

When the osmotic pressure was lowered to 0·3–0·2 strength sea-water these effects were increased: the ectoplasmic border was more marked, though the activity of the sheet pseudopodia lessened progressively till in the end the amœba was almost circular with a clear sheet of ectoplasm surrounding a granular mass. This form resembled the amœbocytes described by Loeb (**25**) as possessing, under similar conditions, a structure resembling ova with a fertilisation membrane. In the amœbæ this resemblance was superficial, because in reality they were not spherical when in this condition, but flattened against the substratum.

Amœbæ could still recover if returned to "outside sea-water" from 0·2 strength sea-water. If, however, the 0·2 strength sea-water was replaced by distilled water they were incapable of recovery. They might not undergo immediate cytolysis, but they swelled till almost spherical.

Sometimes while swollen a number of violent contractions occurred, at each of which water was discharged from the cell; these contractions ended in cytolysis.

Hypertonic Solutions: Type A.

In hypertonic solutions water is abstracted from the amœba. The animals are capable of considerable adjustment to the medium if the osmotic pressure is changed slowly. Figure 3, No. 2, illustrates changes in individual amœbæ accompanying a progressive increase of osmotic pressure.

On raising the solution from 1·0 to 1·2 strength sea-water only slight changes occurred in the amœbæ. The animals became more sluggish, and tended to throw out lateral pseudopodia. The tail-piece sometimes increased in area, and there were more "fine processes" on it.

In 1·2–1·4 strength sea-water the limax form was at first lost; there were several pseudopodia, and these of a characteristic rounded appearance. The fine processes elongated slightly, and they sometimes arose over half the surface of the animal. Later adjustment took place, and the "limax-proteus," or even the limax form, was attained, though often with an enlarged tail-piece.

When the osmotic pressure was raised to 1·5–1·6 strength sea-water the amœba tended to become spherical. Small pseudopodia appeared all over the body (Fig. 3, No. 2); they were more numerous than those formed in 1·4 strength sea-water and consisted largely of clear ectoplasm. The fine processes might appear at any point on the body. A few amœbæ even went into a peculiar "radiosa" or a "lemon" form (Fig. 3, No. 2).

In the "lemon" and similar forms the amœba consisted of a rounded granular mass bearing a few nipple-shaped pseudopodia of clear ectoplasm. In the "radiosa" form the fine processes of the tail-piece increased in size, and often developed at points all over the surface of the rounded granular body of the amœba. The originally limax amœba came more to resemble a naked Foraminiferan than an amœba. There is a strong similarity between these "radiosa" forms and those described by Loeb (**25**) in the amœbocytes of Limulus under similar conditions.

In the 1·5–1·6 strength solution the amœbæ might effect partial adjustment to the medium after some time, but adjustment rarely exceeded the mere limitation of the fine processes to a definite area of the amœba.

In 1·7–1·8 strength sea-water many amœbæ assumed the "lemon" or "radiosa" forms, but the majority consisted of a compact granular mass bearing small clear pseudopodia. It was then impossible to distinguish between the pseudopodia and the enlarged fine processes.

On raising the osmotic pressure to twice the strength of sea-water, the clear ectoplasmic pseudopodia reached the condition seen in the nipples of the " lemon " form. Finally, these pseudopodia lengthened, and in the majority of amœbæ the " radiosa " form was attained. The radiosa pseudopodia might even extend to several times the body length. Some " radiosa " forms contracted the pseudopodia into small droplets, so that they took on a " morulate " appearance (Fig. 3, No. 2). This occurred more readily if the rise in osmotic pressure had been sudden.

Further increase in the osmotic pressure caused great shrinkage without further change in the type of pseudopodia. In and above 1·8 strength sea-water the amœbæ were incapable of reverting to the normal form by adjustment to the medium. Cytolysis did not take place for some hours even in 3·0 strength sea-water, and recovery could take place if this solution was slowly brought back to the strength of ordinary sea-water. Great swelling, usually followed by cytolysis, occurred if amœbæ were suddenly transferred from 3·0 to 1·0 strength sea-water.

It is interesting to note the strong resemblance of the effects of hypotonic and hypertonic solutions on such widely different amœboid individuals, as " Type A " amœbæ and the amœbocytes of Limulus.

Loeb (25) considers pseudopodium-formation is due to liquefaction at the advancing tip of the pseudopodium, followed by gelation at the sides. Liquefaction will necessarily be more limited when the protoplasm is more gelated, and also gelation will occur more readily at the sides of the pseudopodium. For these reasons, when the protoplasm of an amœba is more gelated, we should expect to find long thin " radiosa " pseudopodia, and when more fluid we should expect wide liquid pseudopodia.

Loeb points out that some of the effects of hypotonic and hypertonic solutions can thus be accounted for by assuming that the imbibition of water by the amœbocyte (or the amœba) from a hypotonic solution causes an increased fluidity of the protoplasm resulting in broad liquid pseudopodia. Conversely the loss of water which occurs in a hypertonic solution causes an increase in consistency, so that fine " radiosa " pseudopodia develop. Additional evidence that the effects are due simply to imbibition of water by, or its abstraction from, the protoplasm, and are not due to variation of the concentration of particular ions, is provided by the behaviour of amœbæ which are transferred to normal sea-water after previous adjustment to a hypotonic medium. Under these circumstances the amœbæ often go into a typical " radiosa " form at first, though ultimately recovering the normal limax form (Fig. 3, No. 3). Similarly, radiosa amœbæ which have been kept for some time in 2·0 strength sea-water approach the typical limax form when first put in 1·5–1·6

strength sea-water. The effects of osmotic pressure are due to the altered water-content within the cell.

However, it is difficult to see how mere increased liquefaction of the protoplasm could cause the flattened sheet-like character of the amœbæ in solutions of very low osmotic pressure : a condition very similar to that of leucocytes exhibiting the stereotropic reaction to the substratum. Again, increase in consistency alone can scarcely account for the " morulate " forms sometimes seen in hypertonic solutions, nor can it explain the great length and number often attained by " radiosa " pseudopodia.

We have seen that both the fine processes characteristic of the tail-piece and the true pseudopodia tend to become similar sheet-like extensions of the ectoplasm in a hypotonic medium. We have also seen that both the pseudopodia and the fine processes can become transformed, with but little change in the latter, into the " radiosa " pseudopodia in hypertonic solutions. This suggests that even in normal amœbæ the fine processes of the tail-piece are true pseudopodia, but formed under different conditions.

Taking into account the fluid character of the advancing pseudopodium of the limax amœba on the one hand, and the strong resemblance of the " fine processes " and the " radiosa " pseudopodia on the other, one may be justified in concluding that in normal locomotion water is being imbibed by the protoplasm at the advancing pseudopodium while it is being abstracted from the region of the tail-piece, which therefore tends to form " radiosa " pseudopodia.

The Effect of Osmotic Pressure : Type B.

The effects of changes in osmotic pressure on Type B amœbæ (Fig. 3, No. 4) are essentially the same as on Type A. Activity is only possible within certain limits of osmotic pressure.

The ultimate effect of hypertonic solutions is the assumption of a rugose form by the entire amœba. A " radiosa " form is not developed, and this is possibly correlated with the absence of fine processes on the tail-piece of the normal Type B amœba.

In very hypotonic solutions the endoplasmic granules become condensed into a central mass, the whole amœba swells, and the ectoplasm forms flat sheet-like pseudopodia. The effect is similar to that occurring in Type A under similar circumstances, but the ectoplasmic sheet is not so flattened and the pseudopodial extensions are more rounded.

As in Type A, a certain amount of adjustment is possible to alterations in the osmotic pressure.

Like muscle (**5**) and cilia (**12**) amœboid activity is altered and inhibited

by an abnormal osmotic pressure : for efficient activity there must be a certain water-content in the cell.

The observations suggest that water is imbibed during pseudopodium formation. From the character of the tail-piece this water appears to be abstracted from the hind end. The streaming of the endoplasm would follow as a consequence of this movement of water within the amœba.

Water imbibed during pseudopodium formation probably is not extracted directly from the external medium. On the one hand, a limax form amœba can move for long periods by the continuous extension of a single pseudopodium. If water were imbibed from the outside medium the amœba must continuously increase in volume, whereas the volume seems to remain constant (taking the length and breadth of the amœba as an index of the volume). On the other hand, when an amœba thrusts out a main pseudopodium from the resting condition the size of the resting mass can be seen to undergo progressive reduction as the size of the pseudopodium increases (Fig. 1, No. 3). It might be argued that the volume of the amœba would remain constant though water were imbibed by the pseudopodium from the external medium if a corresponding extrusion of water took place at the hind end. But this would entail a current within the amœba from the pseudopodium to the hind end : a condition the reverse of that observed.

Imbibition of water from the external medium would result in currents in the medium : these currents have not been observed. Currents in the medium have been looked for, since they should be present on the Bütschli-Rhumbler hypothesis of pseudopodium formation by means of a local lowering of surface tension at the surface of the amœba.

(3) THE RELATION OF AMŒBOID ACTIVITY TO HYDROGEN ION CONCENTRATION.

A. Variations of pH associated with Pseudopodium Formation.

The development of an acid reaction in muscle during contraction is well known. The work of Gray (**12**) indicates that the contraction of cilia is probably associated with the production of acid. It seemed possible, therefore, that a change of hydrogen ion concentration might accompany amœboid activity.

In the following experiments the amœbæ were stained with neutral red. This indicator has many advantages :—

(1) It is readily absorbed by living cells.

(2) Homer (17) has shown that the salt and protein errors of this indicator are negligible unless it is employed for very accurate work. Bayliss supports this (4).

(3) The indicator is much less toxic than other indicators (17 and 4).

(4) The range of the indicator is about the neutral point.

(5) Owing to the colour change being from yellow to red in the presence of acids, a local increase in acidity is much more marked than would be the case if the acid reduced the depth of colour (as in phenol red).

Staining was accomplished by the addition of two or three drops of a 0·05% solution of neutral red in distilled water to about 5 c.c. of sea-water containing the amœbæ. As soon as the amœbæ were stained sufficiently for the true tint to be appreciated with the condenser diaphragm well open, the water was changed for clean sea-water.

The pH corresponding to a particular tint was determined by a method described elsewhere (28), the principle of which is as follows. Test tubes are filled with buffer solutions ranging from pH6·6 to pH8·0, and neutral red is added as indicator. A strip of wood carrying the test tubes is hung in the window in front of the microscope. The image of the series of buffer solutions is now focussed in the plane of the object by means of an achromatic condenser. On looking down the microscope the object stained with neutral red is seen in juxtaposition with the image of the series of tubes. By tilting the mirror the images of successive tubes can be brought opposite the object until a tube is found with a corresponding tint.

It is obvious that the accuracy of the method relies entirely upon the change of tint of the indicator with a change of pH and not upon a mere change in the intensity of the colour. It must be admitted that the change of tint in the case of neutral red does not render it an ideal indicator for the method.

Various amœbæ were tested, but only those of Type A and Type C were found to be satisfactory. In all other amœbæ tried, the presence of large granules in great numbers or the presence of large deeply staining bodies in the endoplasm rendered them unsuitable. Moreover, in amœbæ such as Type B the clear cytoplasm took the stain very feebly or not at all.

In Types A and C the minutely granular translucent ectoplasm took the stain fairly evenly. Type A was more suitable than Type C, because the latter normally has a faint yellow colour and sometimes has a few moderate-sized granules in the endoplasm. In both these amœbæ the tint corresponded to a pH within the range of neutral red.

The observations described below refer to Type A, though results obtained with Type C were almost identical.

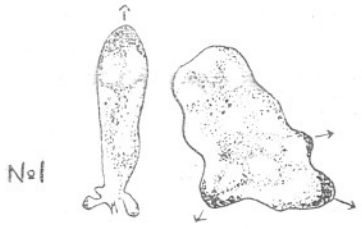
Observations on normal active amœbæ.

The Type A amœbæ were stained with neutral red, though not too deeply. The colour changes described here are obscured by overstaining. The endoplasm stained a dirty yellow, and the ectoplasm stained red.

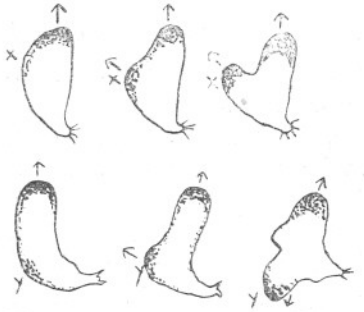
The colouring of the ectoplasm was not even or constant. The colour

FIGURE 4.

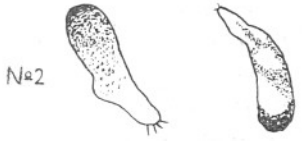
The brightness of the red colour in the protoplasm is represented by the depth of shading.



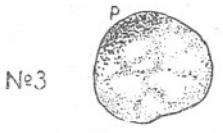
A Type A and a Type C amœba, to show the network.



Three successive stages in two different amœbæ (Type A), cases of apparent local increase in redness before pseudopodium formation (at X and Y).



A sluggish and an active Type A amœba. Note the sharp definition of the red colour in the latter.



Resting Type A amœba, to show the network and greater redness at the pole (P).

pattern took the form of an ill-defined network of dirty red, though brighter in some parts of the network than in others (Fig. 4, No. 1). The network was difficult to draw owing to its constantly changing aspect. In order to be certain that this was not due to local condensations of staining granules the amœbæ were stained with methylene blue. This stained the amœbæ fairly evenly throughout their entire mass, and there was no evidence of a network.

In active amœbæ the anterior and sides of the pseudopodia were bright red. The more active a pseudopodium was, the brighter was its colour.

This was especially the case with eruptive pseudopodia which were sometimes formed. An important feature of eruptive pseudopodia was that they appeared suddenly to gelate at the surface after eruption. The red colour became much more intense on gelation; though afterwards the colour faded back to the tint of the ectoplasmic network.

Dr. E. J. Allen, Director of the Laboratory, and Dr. W. R. G. Atkins kindly allowed me to demonstrate to them the colour change accompanying pseudopodium formation. They both agreed with me as to the definite character of the change.

By the method already described the endoplasm was found to correspond to about pH7·6–7·8, the network of ectoplasm to about pH7·2, and the active pseudopodia to about pH6·8.

The extension of pseudopodia.

Pseudopodium formation was sometimes actually preceded by a slight local increase in the red colour of the ectoplasmic network (Fig. 4, No. 1). But this did not occur invariably, the increase in redness often taking place at the same time or even lagging behind pseudopodium formation.

The bright red of the ectoplasm was sometimes sharply marked off from the underlying endoplasm, though the colour transition from ectoplasm to endoplasm was often gradual; this was especially the case in sluggish limax forms, in which the redness at the anterior end was only of moderate intensity (Fig. 4, No. 2).

The retraction of pseudopodia.

This was accompanied by a change from bright to dull redness. Soon after a pseudopodium ceased activity the apparent pH rose fairly rapidly from about pH6·8 to pH7·0 and thereafter more slowly to pH7·2 (the pH of the network). At times the apparent pH fell very slowly indeed; this was often associated with resumed activity in the pseudopodium.

The resting amœba.

The amœba was spherical in the resting condition. The difference between the colours of the ectoplasm and endoplasm was less marked. The pH of the endoplasm was about pH7·6, while the greater part of the ectoplasm formed a stationary network at about pH7·2. There was sometimes a local concentration in the ectoplasm at about pH7·0 (Fig. 4, No. 3).

The effect of the pH *of the medium: cytolysis.*

The pH of the medium was varied by the addition of N/100 HCl or N/100 NaOH in sea-water. Between about pH9·0 and pH6·0 the internal

hydrogen ion concentration did not seem to fall appreciably. The endoplasm remained at about pH7·6–7·8, whilst the active pseudopodia varied from about pH6·8 to pH7·0.

At a pH of the medium between pH6·0 and pH5·5 the activity was progressively reduced, the amœba usually becoming spherical; at the same time the entire amœba rapidly became very bright red. These effects culminated in cytolysis in a medium between pH5·5 and pH5·0: the ectoplasm of the spherical amœba suddenly became very active, and large fluid spherical pseudopodia were thrown out, accompanied by great endoplasmic streaming. Some of the protoplasm was discharged into the medium, where it coagulated. The pseudopodia often detached themselves from the amœba, so that it became disintegrated into three or four spherical masses of protoplasm.

During this process the colour of the neutral red faded entirely away, leaving the spheres of protoplasm colourless. After a short period of quiescence the separate masses of protoplasm sometimes resumed activity and cytolysed completely, but this did not always occur, the spherical masses sometimes appearing to be coagulated. Once cytolysis had started the amœbæ were incapable of recovery by transference to normal sea-water.

The colour of the stain sometimes redeveloped in the spherical masses for a short time after fading, especially if activity was resumed. Ultimately the colour faded completely away. This fading or bleaching of the neutral red was quite different from the change of the indicator from red to yellow in alkalis: the observations suggested that the stain was chemically altered, possibly by reduction or oxidation.

Cytolysis did not always occur in the manner described above. Sometimes a Type A amœba became spherical at about pH5·5, the surface ectoplasm broke down and the central protoplasm remained as a coagulated mass.

The effect of osmotic pressure.

The internal pH of the amœba was unaffected by osmotic pressure except that reduced activity in hypotonic and hypertonic solutions was accompanied by an appearance resembling that of the normal resting amœba.

General considerations.

Some Type A amœbæ showed the effects very much better than others. This was due partly to differences in staining. After a few hours the stain sometimes collected in small masses in the protoplasm; when this occurred the changes of tint were very difficult to make out, and even seemed to be absent in some cases.

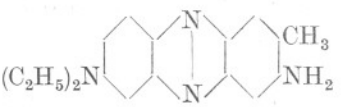
The lighting conditions are very important. A white light is the best, and the diaphragm of the condenser must be opened till the angle of the cone of light from it is equal to the angle of the cone of light entering the objective. Less light than this obscures the colour tint, whilst more light fogs the image.

Apart from differences in staining and lighting conditions there was still considerable variation in the degree to which various amœbæ showed the colour change.

Experiments with other intra-vitam stains.

Atkins (3) has shown that brom-thymol blue can be used as an intra-vitam indicator. This substance only stains amœbæ with difficulty, and is toxic in relatively strong solutions.

By subjecting Type A amœbæ to solutions of relatively moderate strength, the body of the amœba could be stained a pale blue, while the pseudopodia were almost colourless. The effect was very poor, but it does corroborate the neutral red experiments to some extent, because this indicator turns from blue to yellow as the acidity increases.

A di-ethyl homologue of neutral red, 

specially prepared for the author by the Cooper Laboratory, Watford, was also tried.

This substance is a fairly good intra-vitam stain, and is also an indicator. The range is much extended, from pH8 to pH5, the colour changing from yellow to reddish brown. The colour change is not so marked as that of neutral red. Unfortunately, though the stain is readily soluble in fresh-water, sea-water precipitates it almost completely.

Neutral violet (also prepared by the Cooper Laboratory) was also tried. But this substance is a poor indicator and precipitates in sea-water.

The experiments point to the following conclusions: that in these Type A amœbæ the ectoplasm is more acid than the endoplasm, and that pseudopodium formation is accompanied by an acid reaction of the protoplasm. Moreover, the internal pH of the amœbæ varies only slightly, if at all, as the acidity of the medium is raised until a critical pH is reached at which amœboid movement ceases. This cessation of movement is usually followed by cytolysis in Type A.

When drawing conclusions from these experiments it must be borne in mind that, in spite of the small protein error of neutral red, the concentration of protein in the cell may be so great that estimations of the pH by intra-vitam indicators may be very wide of the mark.

It has already been shown that in amœbæ with clear cytoplasm, such as Type B, the stain is not taken up by the cytoplasm but by the included granules. It is almost certain that the stain is taken up by minute granules in Type A amœbæ also, and not by the cytoplasm itself, because unstained transparent pseudopodia can at times be formed even in this amœba.

The pH measured is therefore the pH of the granules and not that of the cytoplasm itself. An assumption that the change in tint is due to the production of acid in the cytoplasm is not necessarily justified ; chemical changes might occur in the granules during the formation of ectoplasm in the pseudopodium. Again, Loeb (**23**) points out that the pH within gelatine particles is quite different from the pH of the surrounding medium owing to the Donnan equilibrium ; the same may hold true for granules in protoplasm.

Were the acid change restricted to granules alone it might be merely incidental to the mechanism of pseudopodium formation, since granule-free pseudopodia can at times be formed.

Chambers (**6**) has found it possible to inject solutions of dyes into the living cell. He finds that under certain circumstances the dyes diffuse through the cytoplasm. It is hoped that in this way indicators such as brom-thymol blue and phenol red may be injected into the cytoplasm, so that changes in the reaction of the cytoplasm itself could be determined.

(B) Amœboid Activity and the pH of the Medium.

In these experiments the velocity of locomotion has been used as a measure of amœboid activity. The energy of amœboid activity is only a function of the velocity if all the energy of pseudopodium formation is directed to locomotion. But more accurate methods of estimating the activity do not seem to be forthcoming.

Most of the experiments were performed on Type B amœbæ. These are peculiarly suited to the method. If placed in a clean dish of sea-water they move for long periods in a typical limax manner by the continuous advance of the single anterior pseudopodium. There is very little tendency to form lateral pseudopodia. Considerable distances, 10 mm. or more, can be covered in a straight line. (It should be mentioned that no evidence was obtained of the wavy path described by Schæffer (**32**) as characteristic of many amœbæ.)

If the conditions of the medium were kept constant the velocity varied but little. The following table (Table 1) gives the velocity at long inter-

vals of two Type B amœbæ in sea-water pH8·1. The only variable factor was the room temperature :—

TABLE 1.

	Time.	Temperature.	Velocity: μ per sec.
	11.45 a.m.	14·0°C	2·29
Type B	0.15 p.m.	14·6	2·40
Amœba (1)	1.00 p.m.	14·8	2·43
	2.00 p.m.	14·4	2·38
	April 13th.		
	(a) 10.45 a.m.	13·4	2·09
Type B.	(b) 3.05 p.m.	15·1	2·18
Amœba (2)	3.15 p.m.	16·4	2·48
	April 14th.		
	(c) 10.30 a.m.	13·4	2·06

In the intervals between the values (a) and (b), amœba (2) had been used for experiments during which it was paralysed with acid. On removal to sea-water pH8·1 complete recovery took place, and the values (b) and later (c) were obtained. The variation in velocity is not great, and always appears to be correlated with the one variable factor, temperature.

Methods.

To determine the effect of various solutions a clean Petri dish on the microscope stage was filled with 50 c.c. of "outside sea-water." A single amœba was then transferred to the dish by means of a fine pipette. After one to five minutes the amœba adjusted itself to the sea-water and moved in a normal limax manner.

A ghost-micrometer (**10**) was placed at such a distance from the microscope that the lines appeared to be 25μ apart when the image was focussed in the plane of the amœba observed.

The velocity was measured with a stop-watch by finding the time taken for the hind end of the amœba to cross one or more divisions of the micrometer. Observations were discarded unless the motion of the amœba was free from irregularities due to sudden changes of direction, and so on.

By turning the Petri dish, the direction of movement of the amœba was kept at right angles, or at 45°, to the divisions of the micrometer. When first transferred to the dish, or when the solution was changed, the amœba moved irregularly ; movement sometimes ceased for a short

time or was abnormally fast, probably owing to direct stimulation. For this reason observations of the velocity were taken after a lapse of about ten minutes, so that adjustment to the new medium might have been completed.

The velocity in a solution was calculated from the mean of ten to forty observations of the time taken to traverse a single interval of the micrometer. Where possible the times taken to traverse blocks of five or ten intervals at a time were taken. In solutions which strongly inhibit amœboid movement, sometimes only a few readings could be obtained.

The velocity remained constant for long periods in various solutions once the initial adjustment had taken place.

Effects of various acids and salts were determined by the addition of successive amounts of 0·01N solutions to the sea-water in the Petri dish. The 0·01N solutions were made up by the addition of 0·1N solutions of the acids or salts in distilled water, to known amounts of " outside sea-water," sufficient 3·0 strength sea-water solution being added to render the solution isotonic with " outside sea-water."

Owing to decomposition of carbonates these 0·01N acid solutions were much weaker than 0·01N acid in distilled water. But the normality of the acid radicle was 0·01N (over and above the concentration of the acid radicle normally present in sea-water).

The pH was determined with the aid of Sœrensen's buffer solutions and the indicators suggested by Clark (**8**). Due allowance was made for salt error. One cubic centimetre only of the solution was taken for pH determination, so that the total volume of the solution should not be greatly changed.

General effects of acids and alkalis.

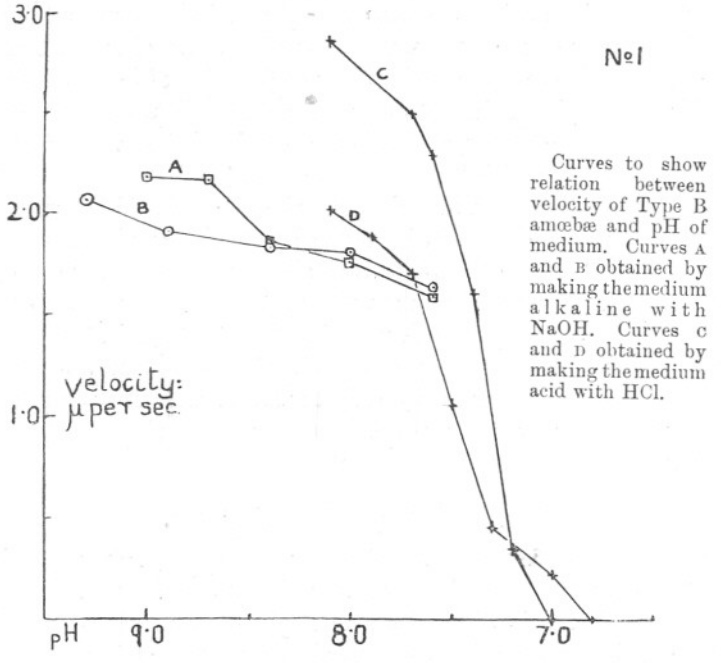
As the hydrogen ion concentration of the medium rises the velocity of the amœba falls, becoming zero at a fairly definite pH. For most acids, a Type B amœba becomes completely paralysed below a critical pH6·8–7·0 ; but no cytolysis occurs till about pH4·0 is reached. In Type A amœbæ paralysis occurs at pH5·0–6·0 and is often accompanied by cytolysis, since this takes place at, or but little below, the pH of paralysis.

This inhibition in acid solutions is completely reversible. A type B amœba paralysed with acid will recover completely on transference to sea-water at pH8·1. The shorter the time of exposure to acid, the more rapid is recovery, though even after twelve hours' exposure at about pH6·8–7·0 recovery commences in about an hour and ultimately becomes complete. The same amœba may be paralysed many times in succession with different acids, and each time the initial velocity is approximately recovered on transference to sea-water at pH8·1 (see Table 1, amœba (2),

also Fig. 6, No. 2). So far as it was possible several experiments were performed on a single amœba, that variations of individual behaviour might be detected ; such variations are found to be small if the conditions are constant.

If normal sea-water is made more alkaline the velocity of an amœba rises slowly up to pH9·6 (Fig. 5, No. 1). Type B amœbæ behave normally in solutions more alkaline than this. But precipitation of the magnesium in the sea-water commences about pH10, and the nature of the solution is thereby greatly modified. For this reason the study of amœboid

FIGURE 5.



movement in solutions more alkaline than this is deferred until the completion of experiments (now in progress) on the effects of the constituent ions of sea-water.

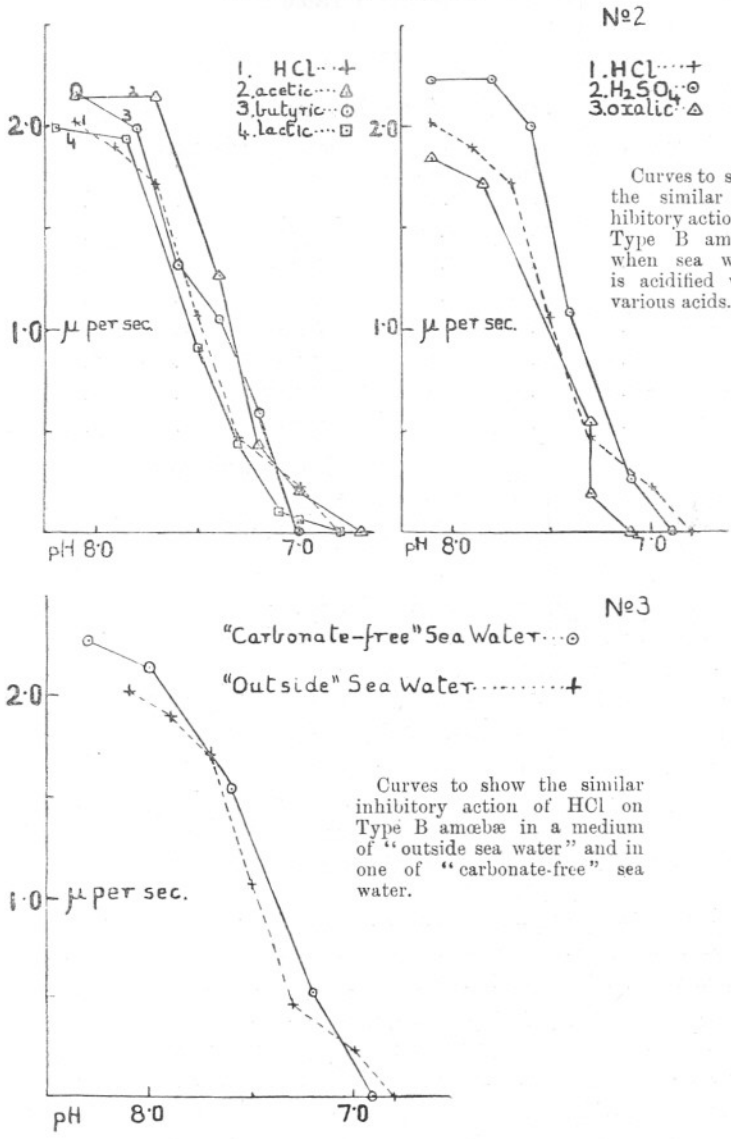
Effect of HCl *and other acids : Type B.*

When a solution of "0·01N HCl in sea-water" is added to sea-water pH8·1 the velocity of the amœba falls slowly as pH7·6–7·5 is approached. The velocity now falls rapidly as the pH is lowered from pH7·5 to pH7·0. Just below pH7·0 the velocity reaches zero (Fig. 5, No. 2).

There is little change in the form of the amœba while the velocity is falling slowly, but when the fall becomes rapid the amœba becomes

shorter and thicker, ultimately losing entirely its elongated shape at pH7·0. The limax form of locomotion continues right up to the paralysis

FIGURE 5 (*continued*).



point, though it becomes more and more difficult. This seems to be due to increasing gelation of the protoplasm, fewer and fewer granules being free to move in the endoplasm. Finally, at the paralysis point itself the

amœba is contracted into an irregular mass the shape of which alters slowly, though even this slow change ceases later.

This contracted phase can be retained for long periods, provided the solution is kept at about pH6·8 (see Table 2).

TABLE 2.

Type B Amœba.

Time. p.m.	Temperature. °C.	pH.	Velocity: in μ per sec.	Time. p.m.	Temperature. °C.	pH.	Velocity: in μ per sec.
3.10	14·0	8·1	2·45	4.45	14·1	7·0	0
3.30	14·0	7·7	2·09	5.00	14·1	7·0	0
3.45	14·0	7·3	0·58	5.30	13·8	7·1	0
4.00	14·5	7·2	0·09	6.15	13·0	7·2	0
4.10	14·5	7·0	0	6.50	13·0	7·3	0
4.15	14·5	6·9	0	7.10	13·0	7·4	0
4.20	14·5	6·8	0	7.20*	13·0	8·1	0
4.35	14·5	6·9	0	7.30	13·0	8·1	0·1
					Lost before complete recovery		

The pH was lowered by adding 0·01N HCl. Variations in pH after the seventh value are due to the evolution of CO_2 by the acid sea-water, the pH rising in consequence. This rise was corrected by further additions of acid sea-water to keep the solution at about pH7·0.

In another experiment an amœba was paralysed at 1.10 p.m. in a solution at pH7·0. Later the pH began to rise, attaining the value pH7·5 at 7.15 p.m. The amœba at the same time partially recovered, the velocity being 0·5μ per second. The solution was now acidified, and paralysis again occurred and continued till 10.20 a.m. next day.

If the hydrogen ion concentration of the sea-water is increased by the addition of 0·01N solutions of the acids, acetic, butyric, lactic, oxalic, or sulphuric, in sea-water, the velocity : pH curves resemble those obtained with hydrochloric acid within limits normally met with in individual experiments (Fig. 5, No. 2).

It might at first be thought that the weak acids, such as butyric, which penetrate the cell rapidly, would alter the form of the velocity : pH curve. But it has already been pointed out that the velocity was measured after the amœba had become adjusted to the medium. Adjustment may take place more quickly with weak acids, but so far this point is undetermined, owing to the irregular movement of the amœba after the solution is first changed.

None the less, it might be assumed that the inhibitory action of acids is partly an immediate surface effect, and that a considerable time must be allowed for an amœba to attain complete equilibrium in an acid

* Changed back to "outside sea water."

solution. But each velocity : pH curve takes from one to five hours to determine, and during the greater part of this time the amœba is in contact with divers strengths of the acid solution. Thus, even were equilibrium attained only slowly there is ample time for acids with various rates of penetration to affect differentially so small a cell, and consequently to alter the form of the velocity : pH curve. However, since the curves are the same for acids such as hydrochloric and butyric, equilibrium must be attained within the time allowed for an amœba to adjust itself to a changed medium.

The similarity of the curves obtained from very different acids suggests that inhibition of amœboid movement in acid solutions is due to hydrogen ions, and not to the acid radicle.

Now 4 c.c. of a 0·01N solution of " acid in sea-water " are required to bring 50 c.c. of sea-water from pH8·1 to pH7·0, the paralysis point for Type B amœbæ. In such an acid solution the concentration of the acid radicle, over and above its natural concentration in sea-water, is therefore

$$0{\cdot}01\mathrm{N} \times \frac{4}{50+4}, \text{ or about N/1300.}$$

If the effects of both strong and weak acids are due entirely to the hydrogen ions and not to the acid radicle, the velocity of the amœba should be unaffected by a concentration of the acid radicle of N/1300, provided the hydrogen ion concentration is kept constant. Table 3 shows that this is the case for the butyrate radicle. In this experiment the concentration of the butyrate radicle was raised by the addition of a solution made up by bringing 0·01N " butyric acid in sea-water " up to pH8·1 with sodium hydroxide.

TABLE 3.

Solution maintained at pH8·1.

Concentration of Butyrate radicle.	Temperature. °C.	Time. p.m.	Velocity. μ per sec.
Nil	14·2	4.25	1·87
N/5100	14·3	4.40	1·87
N/1700	14·3	4.50	1·89
N/1100	14·4	5.00	1·92
N/600	14·3	5.10	1·94
N/350	14·3	5.30	1·90
N/350	13·0	6.20	1·95
N/200	13·3	6.30	1·90
N/100	13·3	6.45	1·71
N/100	13·3	7.15	0·83
N/100	13·0	10.30	0 (cytolysed)

Before the inhibitory effect of an acid solution can be certainly attributed to the hydrogen ions, one other possibility must be investigated. When sea-water at pH 8·1 is acidified to pH7·0 the carbonates are partially decomposed and CO_2 is evolved. Possibly it is the rise in the concentration of carbon dioxide in the sea-water which inhibits amœboid movement. Jacobs (**19**) has shown that owing to the manner and rapidity of its penetration into living cells, carbon dioxide can exert a powerful specific inhibitory effect not shared by other acids.

To test this point, velocity : pH curves were obtained from amœbæ placed in a solution of artificial sea-water from which carbonates had been excluded. The solution was not absolutely free of carbon dioxide, since some of the gas was dissolved from outside air during preparation, but the solution was never in equilibrium with the carbon dioxide in the laboratory air. Carbon dioxide was absorbed from this air even when the solution was acidified to pH7·0, for on standing it became more acid at the surface exposed to the air, as indicated by the colour change of brom thymol blue. However, the amount of CO_2 in the acidified artificial sea-water is very much less than the amount in acidified natural sea-water.

Were the inhibition of amœboid movement due to the production of CO_2 in an acid solution, the very great difference in CO_2 content of acidified artificial and acidified natural sea-waters must cause a great change in the form of the velocity : pH curves.

It is hoped to repeat these experiments later in a closed chamber, where the partial pressure of CO_2 can be controlled absolutely.

The artificial sea-water was made up in the manner described by Allen (**2**), except that no carbonate was added. The solution contained :—

NaCl	28·13 gms.
KCl	0·77 ,,
$CaCl_2$	1·20 ,,
$MgCl_2$	2·55 ,,
$MgSO_4$	3·50 ,,

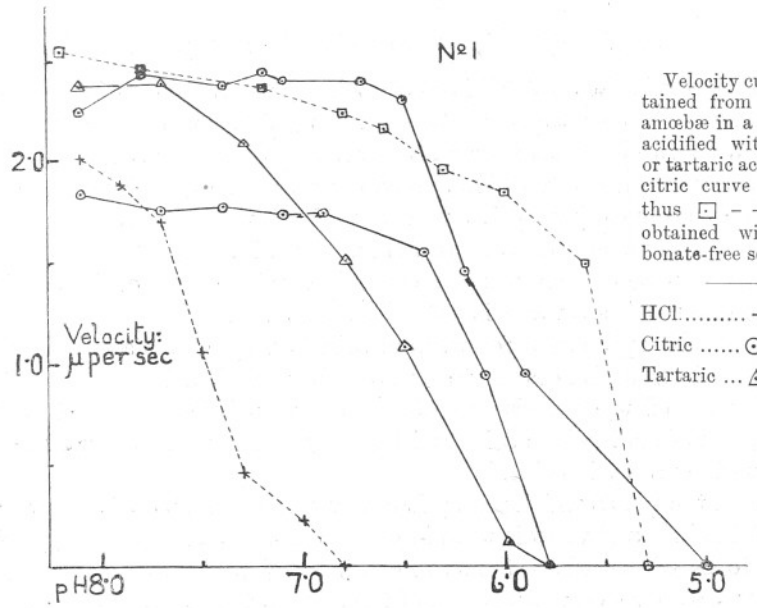
Boiled distilled water, 1000 c.c.

This made a solution of about pH6·8. The solution was oxygenated by shaking with air outside the Laboratory so that a minimal quantity of CO_2 was absorbed. Just before use this solution was brought to pH8·0–8·5 by the addition of pure NaOH solution.

0·005N solutions of acids in this artificial " carbonate free " sea-water were prepared by adding 1·0 c.c. of 1·0N pure acid in distilled water to 199 c.c. of the artificial sea-water. Because there were no carbonates to neutralise, these solutions were more acid than those prepared as already described from " outside sea-water."

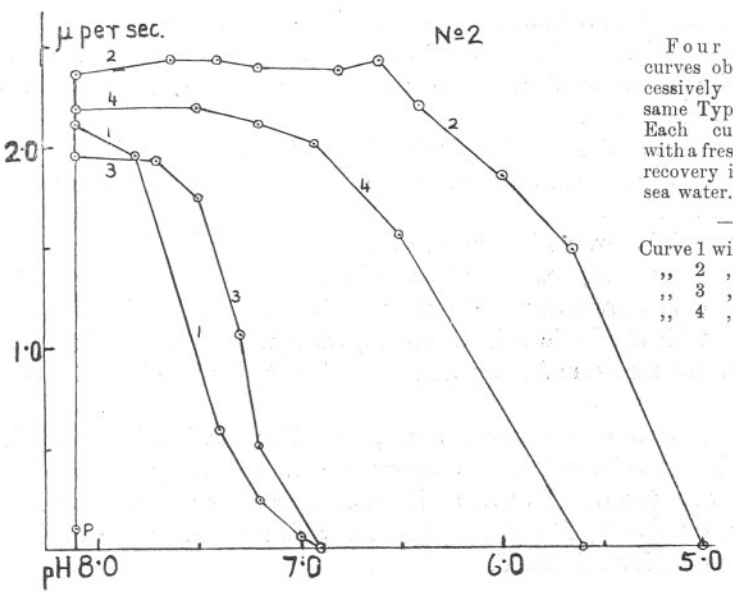
The velocity : pH curves obtained from amœbæ in "carbonate free" sea-water are of exactly the same type as those obtained in normal sea-water (Fig. 5, No. 3).

FIGURE 6.



Velocity curves obtained from Type B amœbæ in a medium acidified with citric or tartaric acids. The citric curve marked thus ⊡ – – –, was obtained with carbonate-free sea water.

HCl..... +
Citric ..... ⊙ and ⊡
Tartaric ... △



Four velocity curves obtained successively from the same Type B amœba. Each curve taken with a fresh acid, after recovery in "outside sea water."

Curve 1 with HCl.
,, 2 ,, Citric.
,, 3 ,, H_2SO_4
,, 4 ,, Tartaric.

The inhibition of amœboid movement in acid sea-water is therefore not due to the increase of the carbon dioxide in the sea-water. Since the inhibition has already been shown not to be due to the acid radicle, it seems that it must be directly related to the hydrogen ion concentration itself.

The effect of citric and tartaric acids: Type B.

When "outside sea-water" is made acid by the addition of a 0·01N solution of citric or tartaric "acid in sea-water," the velocity: pH curves are quite different from those obtained with other acids. With citric acid the velocity remains almost constant from pH8·1 to pH6·5. At pH6·5 the velocity begins to fall rapidly, the amœba becoming paralysed at between pH5 and pH6 (Fig. 6, No. 1).

The same type of velocity: pH curve is obtained from citric acid if "carbonate free" sea-water is used (Fig. 6, No. 1).

The velocity: pH curve for tartaric acid is very like that of citric. As in citric, paralysis does not take place with tartaric acid until pH5–6, But instead of the velocity remaining constant between pH8·1 and pH6·5, as it does in citric acid, it falls fairly slowly from about pH7·5 down to the paralysis point.

Though the pH at which paralysis occurs corresponds to a far greater acidity in citric and tartaric than in other acids, yet the paralysis itself seems to be of essentially the same character, since complete recovery readily takes place on transference of the amœba to sea-water pH8·1.

Figure 6, No. 2, shows four velocity: pH curves obtained from the same amœba. The animal, in sea-water pH8·1, was first paralysed by the addition of hydrochloric acid (curve 1). The solution was then changed for fresh sea-water at pH8·1: complete recovery had taken place two hours afterwards.

The amœba was then paralysed with citric acid (curve 2). The solution was again changed for sea-water at pH8·1, and recovery had taken place one hour later.

After remaining over night in a small vessel containing "outside sea-water," under the microscope, the amœba was next day transferred to a dish full of sea-water at pH8·1; the velocity was normal. It was then paralysed with sulphuric acid (curve 3), after which the solution was again changed for normal sea-water. Recovery took place in under one hour.

The amœba was once more paralysed, but with tartaric acid (curve 4). The solution was changed for sea-water pH8·1 and recovery commenced. Unfortunately the amœba was accidentally lost after the velocity had reached the value "p," but doubtless had this not occurred, complete recovery would have followed.

The curves are typical of their respective classes of acids—and all obtained from the one individual amœba. The slight differences in initial velocity are more or less correlated with temperature (Table 4).

TABLE 4.

Initial solution temperatures for curves in Fig. 6, No. 2.

Type B amœba.		pH.	Velocity. μ per sec.	Temperature. °C.
1st Day	curve (1)	8·1	2·12	12·2
	,, (2)	8·1	2·37	14·5
2nd Day	,, (3)	8·1	1·96	13·0
	,, (4)	8·1	2·20	13·7

From these experiments it seems that the presence of citric or tartaric acid radicles protects Type B amœbæ from the onset of hydrogen ion paralysis which occurs normally at pH7·0. This protection is not broken down till the hydrogen ion concentration is raised about twenty-fold. If this is really a protective effect, the addition of the citrate or tartrate radicle should cause recovery in an amœba paralysed at pH7·0 by means of HCl. Figure 8, Nos. (1) and (2) show that this recovery does take place.

Solutions of 0·01N citric or tartaric acids in sea-water were neutralised with NaOH to pH7·0. An amœba was now paralysed at about pH7·0 by the addition of 0·01N HCl in sea-water. It requires 4 c.c. of a 0·01N acid solution in sea-water to bring 50 c.c. normal sea-water from pH8·1 to pH7·0 ; 4 c.c. of the neutralised citrate (or tartrate) solutions were therefore added to the sea-water at pH7·0, containing the paralysed amœbæ. The amount of citrate (or tartrate) now present in the sea-water is approximately the same as the amount which would have been present had the original sea-water been acidified from pH8·1 to pH7·0 by means of 0·01N citric (or tartaric) acid solution in sea-water.

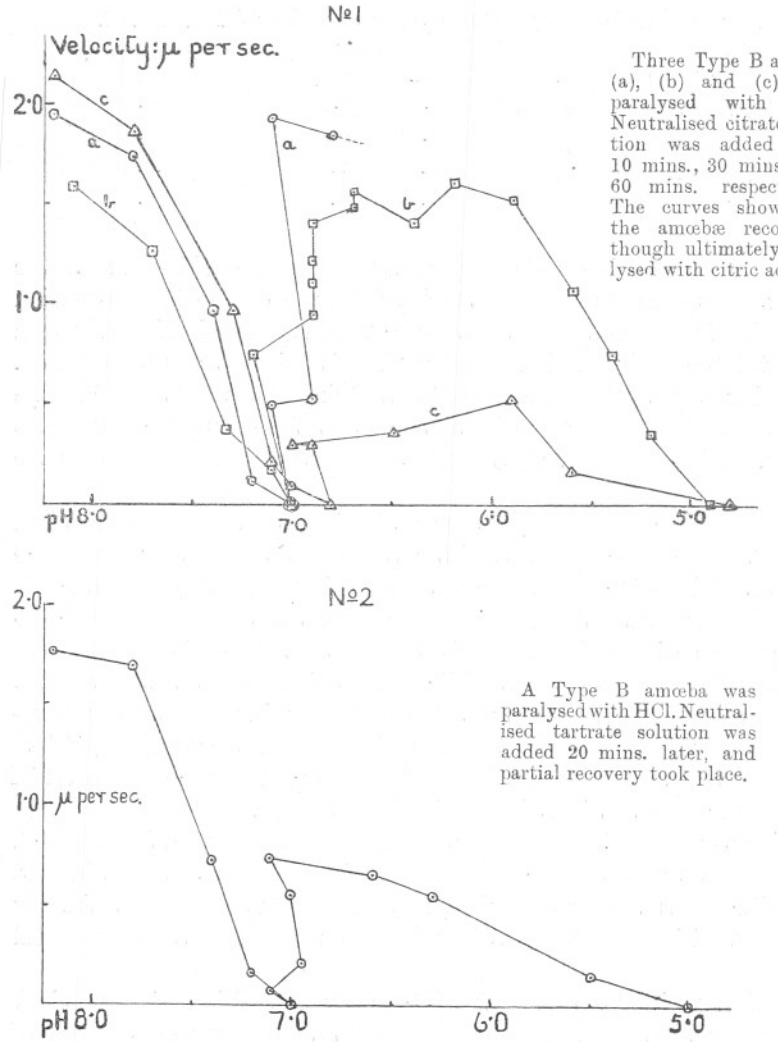
Owing to the evolution of CO_2 the pH now tends to rise above pH7·0. To counteract this some 0·01N solution of citric (or tartaric) acid (not neutralised) was added to the dish, thus bringing the pH down again. By further additions of these acid solutions the pH was lowered still more.

Amœbæ, which recovered at pH7·0 by the addition of neutralised citrate or tartrate solutions, were not paralysed by the addition of citric or tartaric acids till pH5–6, the normal paralysis point for these solutions.

In curve (a), Fig. 7, No. 1, the neutralised citrate was added ten minutes after paralysis with HCl. Recovery was complete one hour later. In curve (b) the citrate was added thirty minutes after paralysis

with HCl, and recovery did not commence for nearly one hour. Recovery was not complete till a certain amount of 0·01N citric acid solution in sea-water had been added—sufficient to raise the hydrogen ion concentra-

FIGURE 7.



Three Type B amœbæ (a), (b) and (c) were paralysed with HCl. Neutralised citrate solution was added after 10 mins., 30 mins., and 60 mins. respectively. The curves show that the amœbæ recovered, though ultimately paralysed with citric acid.

A Type B amœba was paralysed with HCl. Neutralised tartrate solution was added 20 mins. later, and partial recovery took place.

tion to pH6·7 : this was two hours after the commencement of recovery. In curve (c) the citrate was added one hour after paralysis. Recovery commenced in about one hour, but was never complete. The highest velocity after recovery was reached two hours after its commencement,

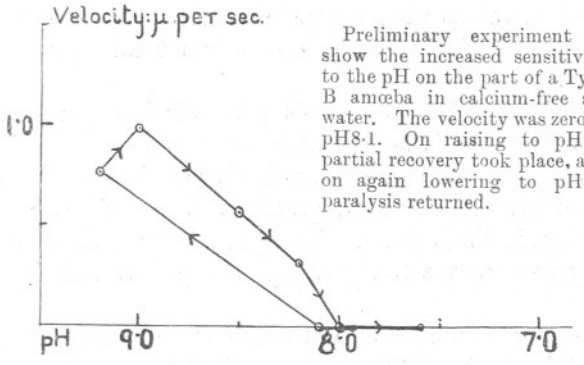
when sufficient 0·01N citric acid solution had been added to raise the hydrogen ion concentration to pH5·9.

The addition of neutralised tartrate solution also causes recovery in Type B amœbæ paralysed at pH7·0 with HCl (Fig. 7, No. 2).

There seems to be no doubt that these results are due to a protective effect of the citrate and tartrate radicles. This protective effect does not seem to be related to the basicity of the acid, since behaviour is normal in sulphuric and oxalic as well as in the monobasic acids. Moreover, it does not seem to be related directly to the presence of the >CHOH group as such, because normal behaviour occurs in lactic acid.

Gray (13) has shown that citrates and tartrates have a unique effect

FIGURE 8.



Preliminary experiment to show the increased sensitivity to the pH on the part of a Type B amœba in calcium-free sea water. The velocity was zero at pH8·1. On raising to pH9·2 partial recovery took place, and on again lowering to pH8·0 paralysis returned.

upon the cilia of Mytilus gills, but the effect is not protective, it is inhibitory (at pH7·8). In the present experiments the citrates and tartrates have never exceeded a moderate concentration, and have always been in the presence of the normal anions of sea-water at their usual concentration: in Gray's experiments the normal anions were entirely replaced by citrate or tartrate. It is probable that the action of these acid radicles is quite different under these two sets of conditions.

However, Gray points out that in the presence of citrates and tartrates the calcium in sea-water is probably not present in its ionic form, and he brings evidence to show that the effects of these acid radicles on ciliary activity are due to this absence of the calcium ion. In view of this it should be mentioned that from experiments still in progress on the effects of ions on amœboid activity, it has been found that the behaviour of Type B amœbæ in calcium-free sea-water bears no resemblance to their behaviour in the experiments with citrates and tartrates. The behaviour of the amœbæ in calcium-free sea-water seems to be analogous to the behaviour of cilia under like conditions, as described by Gray (13). The amœbæ are very sluggish in calcium-free sea-water at pH8·1,

but become active when the solution is made more alkaline (Fig. 8, p. 55), though the velocity is below normal. Absence of calcium, in fact, seems to increase the sensitivity to hydrogen ions, the critical pH being raised from pH7·0 to pH7·6–8·0. This is the very opposite of the effects observed in the citrate and tartrate solutions. For the present the peculiar effects of citrates and tartrates must go without an explanation.

The effects of acids: Type A.

The movement of Type A amœbæ is much less regular than that of Type B. Velocity measurements had to be taken by averaging a large number of readings obtained across single divisions of the micrometer; the movement rarely proceeded uninterrupted for five successive divisions. Also, velocity observations with the same amœba under the same conditions differed more widely among themselves than in the case of Type B amœbæ.

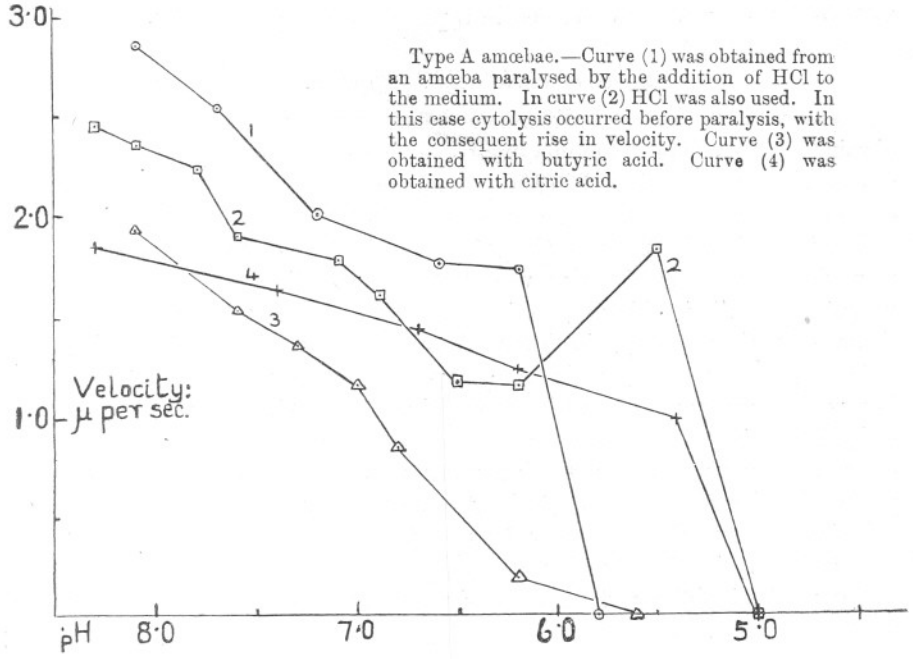
The velocity of Type A amœbæ falls gradually between pH8·1 and about pH6·5, and from this point rather more rapidly, becoming zero between pH6 and pH5. The paralysis point is therefore well below that of Type B amœbæ. In Type A, paralysis is sometimes reversible, but usually cytolysis takes place. The pH of cytolysis is only just below, and in some cases actually above, the pH at which paralysis occurs.

Figure 9 shows velocity : pH curves obtained from Type A amœbæ in sea-water acidified with hydrochloric and butyric acids respectively. Butyric acid seems to be rather more effective than hydrochloric, the critical pH being a little higher. The difference is, however, within the limits of variation for Type A.

In some amœbæ cytolysis began before the paralysis point had been reached. When this occurred there was a sudden large rise in the velocity accompanied by marked changes in the amœba (Fig. 9). The surface of the protoplasm became more rounded. The tail-piece, instead of having the usual rugose appearance, began to cytolyse, so that a mass of coagulated protoplasm was carried at the hind end of the amœba. The "fine processes" of the normal tail-piece were absent, but in their place large droplet pseudopodia were formed. These were rapidly extended and retracted and even became detached from the amœba (Fig. 10, No. 1).

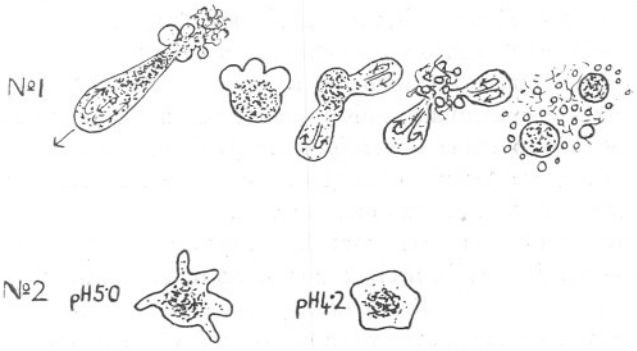
The endoplasmic streaming was very violent, but the velocity though much increased did not rise in proportion. The ectoplasm of the under surface continually slipped from its hold on the substratum, so that although activities normally associated with movement proceeded at a great speed yet locomotion was very inefficient.

FIGURE 9.



Type A amœbae.—Curve (1) was obtained from an amœba paralysed by the addition of HCl to the medium. In curve (2) HCl was also used. In this case cytolysis occurred before paralysis, with the consequent rise in velocity. Curve (3) was obtained with butyric acid. Curve (4) was obtained with citric acid.

FIGURE 10.



No. 1.—Changes in a Type A amœba when cytolysis in an acid medium precedes paralysis. The first figure illustrates the form during the period of increased activity.

No. 2.—Type A: to show changes in form below the point at which the velocity becomes zero when citric acid solution is added.

Ultimately locomotion ceased. The endoplasmic streaming still continued, and large droplet pseudopodia formed. Complete cytolysis followed in the manner described in a previous section of the paper.

Effect of citric acid: Type A.

There was no marked difference between the velocity : pH curve obtained from a Type A amœba in citric and in other acids. Locomotion ceases at a rather lower pH in the presence of citric acid, but this pH is close to the limit of variation for the paralysis pH in HCl (Fig. 9).

But in citric acid the cessation of locomotion does not mean a complete paralysis of amœboid movement. Pseudopodial activity, though progressively diminishing, sometimes continues down to pH4·2. The character of the pseudopodia changes, however. Instead of the formation of the single limax pseudopodium, many pseudopodia are formed. These become blunter as pH4 is approached (Fig. 10, No. 2). The translucent endoplasm with its minute granules concentrates into a central mass, the ectoplasm at the same time becoming relatively clear. Ultimately pseudopodial activity ceases at about pH4·0, when the amœba is almost spherical. Cytolysis follows, and the ectoplasm is destroyed, leaving a central coagulated mass of protoplasm.

The protective effect of citrates is far less marked in Type A than in Type B amœbæ.

DISCUSSION AND CONCLUSION.

In many respects amœboid activity resembles that of cilia and muscle. The protoplasm of the ectoplasmic tube of a limax amœba is contractile. Contractility is more marked in the pseudopodia of the Foramenifera and Difflugia ; so much so that Dellinger (**9**) has suggested that all amœboid activity is due to the contraction of a semi-permanent reticulum pervading the entire individual. This suggestion fails when the movement of obviously fluid amœbæ is considered. Nevertheless some degree of contractility is characteristic of all forms of amœboid activity, just as it is of ciliary (**12**) and of muscular activity.

The osmotic pressure experiments show that the water-content of the cell must be within certain limits for efficient amœboid activity. Gray (**12**) has shown that this also holds for ciliary activity, and the same thing applies to muscle (e.g. the work of Carlson on the heart of Limulus (**5**).)

All three forms of contractility are inhibited by raising the hydrogen ion concentration (**12**) (**4**), and this inhibition is reversible.

The production of acid in muscular activity is well known, and Gray (**12**)

has inferred that the same thing occurs in ciliary activity. The foregoing experiments with neutral red indicate that an increase of hydrogen ion concentration also occurs during pseudopodium formation, though it has been pointed out that this conclusion must be accepted with caution. However, the parallel between the inhibition by acids of amœboid and of other forms of contractility does support this.

Whereas contractility is well marked in muscle, cilia, and certain specialised amœboid individuals, it is less marked in amœbæ with fluid protoplasm. The earlier hypotheses to account for amœboid movement concentrated on this fluid character of the protoplasm; they assumed that an amœba could be considered as a fluid drop in a medium with which it was immiscible. It was natural, therefore, to assume that the energy of amœboid movement was derived from surface tension changes.

According to Berthold the amœba flowed passively under the influence of local variations of surface tension between the fluid protoplasm and the substratum. Such a passive reaction of the amœba cannot explain all the phenomena observed, and, as Berthold himself realised, the hypothesis breaks down for free pseudopodia projected into the medium.

Rhumbler (**30**) suggested that a pseudopodium was formed by a local lowering of surface tension at the surface of the amœba. This was brought about by hypothetical minute droplets of "enchylema," which burst on the surface of the ectoplasm. The endoplasm then flowed towards the region of lowered surface tension, and, turning outwards at the tip of the pseudopodium, flowed backwards along the surface, having been changed into ectoplasm by the "ento-ectoplasmic process." Rhumbler called this streaming of the protoplasm a "fountain current." The advantage of this hypothesis over that of Berthold was that it assumed pseudopodium formation to be an active process on the part of the amœba.

Great difficulties are in the way of surface tension hypotheses of amœboid movement. In the first place, the surface of protoplasm must be supposed to be fluid. The microdissection studies of Seifriz (**33**), Chambers (**6**), and Kite (**21**) all go to show that whereas the endoplasm is fluid, the ectoplasm is gelated at the surface, though the thickness of the gelated layer seems to vary in different cases. It is difficult or impossible for a body with a solid surface to alter its form under the influence of surface tension. Moreover, the existence of the filose pseudopodia of the Foramenifera shows that in this case, at least, surface tension is negligible. Were it not so, the pseudopodia would be unstable; they would become moniliform, or even break up into droplets—a change which actually occurs in the pseudopodia of Polystomella on cytolysis with sodium hydrate.

Apart from these considerations Mast and Root (**26**) have shown that surface tension cannot supply the energy required to account for the relatively great force exerted by the pseudopodia of amœba. The pseudopodia can actually pinch a *Paramœcium* in two.

Though the surface tension hypothesis offers an explanation of the movement of fluid amœbæ, it breaks down in cases where contractility is highly developed. It fails in the case of Difflugia which Dellinger (**9**) has observed to move by the extension and retraction of pseudopodia. Cases such as these are the very ones that serve to link amœboid movement with other forms of contractility, and must be taken into account in any complete hypothesis of amœboid movement.

Rhumbler realised that the surface tension hypothesis could not account for the movement of amœbæ with a firm ectoplasm, such as *A. verrucosa*. He suggested that in these cases movement was the result of a local liquefaction of the ectoplasm. In a later paper (**31**) he works out this hypothesis in greater detail on *A. terricola* and allied forms.

Hyman (**18**) extends this new hypothesis to cover all forms of amœboid movement. She points out that microdissection evidence shows that in all amœbæ the ectoplasm is gelated, though local liquefaction is present during pseudopodium formation. She therefore suggests that in the formation of a pseudopodium there is a change from the gel to the sol state in the ectoplasm. Conversely in the retraction of a pseudopodium there is a change from the sol to the gel state (cf. Chambers (**7**)).

So far as concerns the fluid nature of the protoplasm in the advancing pseudopodium, my own observations are in agreement with those of Hyman. But in limax amœbæ continuous movement also demands the "ento-ectoplasmic process." The essential feature of the limax movement is the formation of fluid ectoplasm at the anterior end of the advancing pseudopodium by the "ento-ectoplasmic process." This ectoplasm, becoming gelated at the sides of the pseudopodium, forms the contracting ectoplasmic tube, the gelated ectoplasm being absorbed again into the endoplasmic stream within the hinder end of the amœba. The streaming of the protoplasm agrees with the "fountain-currents" of Rhumbler (**30**), except that there is no backward *current* at the sides of the amœba, but a gelated ectoplasmic tube, which passes back to the hind end as it contracts. The description of the limax movement given in this paper agrees with that of Schæffer (**32**), except that he does not consider that the endoplasmic stream flows passively under the pressure of the contracting ectoplasmic tube.

The experiments of Loeb (**25**) on the effect of osmotic pressure on amœbocytes, as well as my own experiments on its effect on marine amœbæ, support the conclusion that pseudopodium formation is accompanied by local fluidity of the ectoplasm. This conclusion offers an ex-

planation of the behaviour of pseudopodia in solutions of different osmotic pressures. But the experiments go further : the similarity of the condition of the tail-piece of an amœba to that of the entire amœba when water has been abstracted from it, together with the fluid character of the advancing pseudopodium, suggest that water is actually abstracted from the hind end of the amœba, and imbibed by the protoplasm at the anterior end. A water current is therefore set up towards the anterior end. This current, aided by the contraction of the ectoplasmic tube, would give rise to the endoplasmic stream.

Schæffer (32) considers the energy of amœboid movement to be derived from the streaming endoplasm itself. But, as he points out, where pseudopodia are highly contractile this streaming does not seem to accompany amœboid activity. Again, a pseudopodium when first formed may consist entirely of swelling ectoplasm, the endoplasmic granules actually being pushed inwards (Fig. 1, No. 4). The endoplasm does not burst into the pseudopodium till later. Jennings (20) also describes the bursting of the endoplasm into an ectoplasmic pseudopodium.

If it is assumed that amœboid activity is brought about by the imbibition and abstraction of water with consequent swelling and contraction of the protoplasm, both the movement of amœbæ with fluid protoplasm, and the contractile movements of Difflugia and other forms, become special cases of the same general phenomenon.

Fürth (11), in a theoretical consideration of the subject, has attempted to unite both the imbibition and the surface tension theories. He calls attention to the effects of the addition of acid to a protein suspension. A myosin suspension in the presence of acid increases in dispersion, and there is a tendency to imbibe water : at the same time the surface tension falls.

Fürth supposes a substance, "lactacidogen," to be present in the protoplasm. This substance is broken down locally, forming lactic acid. The increase in acidity causes imbibition of water from the surrounding protoplasm, with the result that a pseudopodial projection tends to be formed. This projection would be surrounded by a ring-shaped depression, owing to the abstraction of water in the neighbourhood of the projecting pseudopodium. The acid is supposed to cause local lowering of surface tension at the surface of the pseudopodium ; the surface tension over the rest of the amœba therefore tends to push out the swelling protoplasm of the pseudopodium, at the same time effacing the depression round its base.

Fürth considers that all forms of amœboid activity could be explained by this hypothesis, including the filose pseudopodia of the Foramenifera.

But the essential feature of his hypothesis is that the pressure of the swelling pseudopodium is acting against the pressure due to the surface tension over the surface of the amœba. These two pressures must therefore be of the same order of magnitude, and as we have seen from the observations of Mast and Root (**26**), sufficient energy cannot be derived from pressures of this order. Moreover, the same objection holds here that held against Rhumbler's surface tension theory ; the presence of gelated ectoplasm over the body of the amœba must render the mechanical effects of surface tension negligible. As in Rhumbler's theory, it is impossible to see how the long filose pseudopodia of the Foramenifera can remain stable unless the forces due to surface tension are too small to produce an effect.

With regard to an increase in acidity during pseudopodium formation Fürth's hypothesis is very suggestive. The writer, independently, had come to the same conclusion from the results of the experiments described in this paper. A rise in acidity does seem to occur during pseudopodium formation. Moreover, the importance of the hydrogen ion concentration in relation to amœboid activity is probably general, because the activity not only of these amœbæ but also, according to de Haan (**15**), of leucocytes varies with the pH.

Hyman's observations (**18**) also may indicate that a chemical change is occurring in an advancing pseudopodium. She finds that the tips of the youngest pseudopodia are the first parts of the amœba to cytolyse in dilute KCN. She argues on Child's hypothesis that the rate of metabolism is higher at these places than elsewhere.

We have seen that the inhibitory action of acids on amœboid movement is reversible, and that it is directly related to the hydrogen ion concentration. Gray (**12**), in considering the inhibition of ciliary activity by an acid medium, points out that according to Kondo the rate at which lactic acid is produced from its precursor depends upon the hydrogen ion concentration. If the production of acid in amœboid activity be due to a chemical mechanism similar to that which produces lactic acid in muscle, the inhibitory effect of an acid medium may be due to this cause.

There is possibly another way in which increased acidity of the medium may inhibit amœboid movement. The rise in hydrogen ion concentration may increase the gelation of the ectoplasm. Gelation may proceed too rapidly in the advancing pseudopodium where ectoplasm is being formed from endoplasm. The resistance to amœboid movement would thus increase in proportion to the penetration of the acidity of the medium.

Before investigating this second possibility further, the effects of an acid medium on the surface tension must be considered. Fürth, as we have seen, suggests that the surface tension at the surface of the amœba

will fall in the presence of acid, on the analogy of the effect of acid on a suspension of myosin. But living protoplasm is very different from a simple protein suspension. There is evidence that the cell surface is not of a protein, but of a lipoid nature (**4**).

The effect of a rise in hydrogen ion concentration on a lipoid-water interface will be very different from the effect on a protein-water interface. Hartridge and Peters (**16**) have shown that for an olive oil-water interface the surface tension increases, and increases with great rapidity, as the hydrogen ion concentration rises ; near neutrality there is a rise of 35% for a fall of 1·0 of pH. They point out that this is in keeping with Langmuir's observations on the effects of acids and alkalis on films of oil and of fatty acids spreading on water.

The lipoid surface of the cell would probably behave in a similar manner ; a rise in hydrogen ion concentration, instead of diminishing the surface tension at the surface of an amœba, would cause it to increase considerably.

Schæffer (**32**) brings evidence to show that an increase in surface tension does occur at an advancing pseudopodium. He shows that a thin surface tension layer moves over the amœba towards the advancing anterior end. It is probable, therefore, that contrary to Fürth's assumption, work is actually done against the surface tension when a pseudopodium is formed.

Assuming from experimental evidence that there is an increase of acidity in pseudopodium formation, and assuming that a lipoid film covers the amœba, the following hypothesis to account for amœboid movement suggests itself.

The production of acid at some point in the protoplasm causes water to be imbibed : this assumption has also been made by Fürth. Proctor (**29**) has shown that acid causes imbibition of water by gelatine ; and he points out that this occurs both in gelatine gel and in the gelatine particles of a gelatine sol.

The above assumption implies that the protein constituents responsible for the imbibition are in the neighbourhood of the iso-electric point (cf. Loeb (**23**)).

The swelling resulting from the imbibition of water will cause a pseudopodium to be protruded, so that the surface is increased by stretching the surface layer. As swelling continues the protoplasm pushes beyond the old surface layer, and a fresh surface of fluid protoplasm is continuously exposed to the medium at the advancing anterior pseudopodium.

Since the acidity has raised the surface tension at the lipoid interface between the protoplasm and the medium, proteins and possibly other substances will become condensed at the freshly formed surface in order

to lower the free surface energy. This follows from Gibbs' principle, which shows that substances which lower the surface tension tend to concentrate at the surface (**4**). A familiar instance of the same principle is the surface coagulation of a solution of albumen.

Thus as the fresh surface of protoplasm is formed at the sides of the advancing pseudopodium, the protoplasm immediately beneath the surface will tend to gelate, forming ectoplasm. This is perhaps the explanation of the " ento-ectoplasmic " process.

As locomotion of the amœba proceeds and the pseudopodium continues to advance the already formed ectoplasm approaches the hind end of the amœba. The acidity at the same time diminishes, owing either to neutralisation and diffusion, or possibly, as in muscle, to partial reconversion into a precursor substance. The reduction of acidity will cause the reversal of imbibition, that is, syneresis and loss of water by the swollen particles of protein ; evidence for this loss of water has already been advanced. Moreover, the surface tension will fall and the concentration of substances at the surface will diminish. The contraction of the " ectoplasmic tube " and the absorption of protoplasm into the endoplasmic stream might be explained in this way. These effects, combined with the imbibition of water taking place at the anterior end of the amœba, would give rise to the endoplasmic stream.

The inhibitory action of acids in the external medium follows on this hypothesis because the surface tension will be raised ; there will be an increased condensation of substances at the surface. At the pH of paralysis this condensation will be so great and take place so rapidly where fresh surface is exposed on the advancing pseudopodium, that the swelling protoplasm is unable to overcome the resistance of the now gelated surface.

It is interesting to note that the imbibition of water by a protein solution in acid is accompanied by an increase in viscosity (**23**). Possibly it is owing to this increase that the granules of the streaming endoplasm so often seem to be checked behind the clear protoplasm of the advancing pseudopodium.

The advantage of this hypothesis is that the same explanation is offered to account for the activity of amœbæ with a fluid protoplasm and for the activity of those with highly contractile pseudopodia of high consistency. The swelling and syneresis of a protein according to the hydrogen ion concentration occurs whether the protein is in the sol or gel state (**29**).

Perhaps, as Fürth suggests, lactic acid is produced during pseudopodium formation. But this is a bold assumption in view of the fact that the carbohydrate-lactic acid mechanism of contraction has only been studied in highly specialised muscular tissues. It is possible that

there is an unspecialised chemistry of contraction in the unspecialised activity of amœba.

These suggestions rather overstep the basis of the existing knowledge concerning amœboid movement. They are only intended to form a working hypothesis to guide further research.

SUMMARY.

(1) Marine limax amœbæ were used for these experiments. A limax amœba may be looked upon as a contracting tube of gelated ectoplasm, closed at the posterior end; the anterior end is occupied by the fluid ectoplasm of the advancing pseudopodium. The fluid endoplasm streams forward through this tube from a place of liquefaction within the posterior end of the amœba. On reaching the anterior end, the streaming endoplasm apparently forms the fluid ectoplasm of the advancing pseudopodium. This fluid ectoplasm continuously adds to the contracting tube by gelation at the sides of the pseudopodium.

(2) As in the activity of muscle and cilia, amœboid activity can only take place provided the water content of the cell is within certain limits. Solutions with an abnormal osmotic pressure produce marked changes in the character of the pseudopodia: these changes can in part be accounted for, by the increased gelation of the protoplasm owing to the abstraction of water in hypertonic solutions on the one hand, and on the other by the increased fluidity owing to imbibition of water by the cell in a hypotonic solution.

(3) Comparison of the normal amœba with those in hypertonic and hypotonic solutions suggest that water is abstracted from the hind end of an active amœba, while the fluid protoplasm of the anterior pseudopodium imbibes water.

(4) Experiments with certain amœbæ stained with neutral red indicate a rise in hydrogen ion concentration in an active pseudopodium. The ectoplasm seems to be more acid than the endoplasm. For reasons given in the text it is not certain that the effects indicate the production of acid in the cytoplasm itself; changes in the minute stained granules might alone be involved.

(5) Experiments were performed to determine the relation between the velocity of an amœba and the pH of the medium. An acid

medium inhibits amœboid movement, the velocity reaching zero at a fairly definite pH for each kind of amœba.

As in muscle and cilia, this inhibition in acids is reversible, provided the acidity be not too great. Amœbæ paralysed with acid recover completely on transference to sea-water at pH8·1.

(6) The velocity of a Type B amœba, which has become adjusted to the medium, falls slowly as pH7·6 is approached and afterwards more rapidly, complete paralysis occurring at pH6·8–7·0. In Type A amœbæ the velocity falls gradually to about pH6·5, and then more rapidly to pH5–6, where paralysis occurs.

In Type A, cytolysis usually occurs near the paralysis point. Sometimes cytolysis occurs before this point is reached: this is accompanied by a sharp rise in the velocity, together with marked changes in the amœba.

(7) The same velocity : pH curve is obtained whether the medium be acidified with hydrochloric, acetic, butyric, lactic, sulphuric, or oxalic acids. The inhibition of amœboid movement in an acid medium depends neither on the acid radicle added nor on the carbon dioxide evolved by decomposition of the carbonates of the sea-water: it depends upon the hydrogen ion concentration.

(8) Citrate and tartrate, however, exert a protective action on Type B amœbæ, and possibly also on Type A, though to a much smaller extent. In the presence of these acid radicles the paralysis point of Type B amœbæ is shifted from pH7 to pH5–6. In spite of this, inhibition with citric and tartaric acids is reversible, just as it is in other acids.

(9) The protective action of citrate and tartrate seems to be unrelated to the basicity of the acids, because sulphuric and oxalic acids produce the same kind of velocity : pH curve as the monobasic acids. Nor does the action seem to be directly related to the presence of a =CHOH group, because lactic acid gives a normal velocity : pH curve.

(10) The protective action is not due to the absence of calcium ions through the formation of complex molecules between calcium and the citrate or tartrate radicle. Preliminary experiments show that absence of calcium raises the paralysis point of Type B amœbæ to pH7·6–8·0, the opposite effect to that of citrate or tartrate. The action of these radicles cannot yet be explained.

(11) A working hypothesis is suggested to account for amœboid movement. The local production of acid causes imbibition of water by the protoplasm. This causes swelling, and a pseudopodium is protruded. For reasons given in the text it is suggested that the acid raises the surface tension over the advancing pseudopodium. Substances in the protoplasm will now concentrate on the freshly formed surface at the sides of the advancing pseudopodium, in order to lower the surface energy. This would account for the formation of the gelated ectoplasmic tube by the "ento-ectoplasmic" process.

As the gelated tube passes back towards the hind end of the amœba the acidity disappears; the imbibed water is lost by syneresis with a resulting contraction of the protoplasm. At the same time the surface tension falls and the surface concentration of substances diminishes. This would account for the contraction of the ectoplasmic tube and its internal absorption into the endoplasmic stream.

The imbibition of water at the anterior pseudopodium and the syneresis at the posterior end, together with the force of the contracting tube of ectoplasm, would cause the endoplasmic stream to be driven forwards.

I wish to thank Mr. J. Gray, of King's College, Cambridge, with whose kind help and advice this research was commenced.

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The Food of Plankton Organisms. II.

By

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With Figures 1–12 in the Text.

LAST year preliminary results on the feeding of some of the commoner plankton organisms were published (1922). Further progress is made this year, more especially on the living animals, chiefly cœlenterates, kept in the plunger jars. The results of these experiments, specially undertaken to find out whether medusæ naturally caught and ate small fishes, answer the question undoubtedly in the affirmative. A large number of the smaller medusæ were kept alive, and most of these were seen to catch and eat fishes. The usual method of catching the food is with the outstretched tentacles, which, drawn out to very fine threads, react when anything living touches them, stinging the prey with their stinging cells; the tentacles then contract and helped by others, and often also by the lips and sides of the umbrella, manage to convey the food to the mouth, from which it reaches the stomach and is digested. A certain amount of selection is apparent, for the tentacles often reject food. Moreover, medusæ of one species do not as a rule eat one another, although taking other species voraciously. If many small fishes are available the smaller crustacea are neglected by many of the medusæ, although these may be taken when other food is scarce. *Sagitta bipunctata* and *Tomopteris helgolandica* are popular with nearly all those that can eat fishes. Certain medusæ, e.g. *Sarsia tubulosa* and *S. prolifera*, have never been seen to eat anything but crustacea (copepods or decapod larvæ), and fishes have not been seen inside them.

In some cases, although the medusæ were not kept alive, they were taken alive from the tow-nets when eating fishes. It was surprising how the small specimens (hardly a mm. across) could eat fishes much larger than themselves, especially *Rathkea octopunctata*, which was eating larval Herring and Sprat.

Pleurobrachia pileus will eat fishes eagerly, and has been kept alive and seen to catch them. From the Young Fish Trawl some very large examples were taken by the *George Bligh* and kindly given me by Mr.

Clark, which had been feeding abundantly on larval and newly hatched Herring, also on Plaice eggs and newly hatched Plaice.

Sagitta bipunctata is already known to be an enemy of the youn fishes, especially Herring. Many of these feeding on Herring were taken by the *Salpa* in January, 1923, in the tow-nets and preserved immediately in formalin. These showed the young Herring being taken by the powerful jaws of Sagitta. Many Sagitta were seen with the remains of Herring inside. Further specimens were taken by the *George Bligh* and given me by Mr. Clark.

Tomopteris helgolandica has been found with fine unicellular food inside, but this year it was seen to eat a Sagitta. More interesting still is the fact that it also eats young Herring. Two specimens from the *George Bligh*, given me by Mr. Clark in January, 1923, contained distinct remains of these fishes.

The following plankton animals have been found to eat fishes :—

Aurelia aurita (from the Scyphistoma and ephyra up to at least $1\frac{1}{4}$ inches).

Chrysaora isosceles.

Æquorea sp.

Cosmetira pilosella.

Phialidium sp. (chiefly *hemisphericum*).

Obelia geniculata.

Laodicea undulata.

Rathkea octopunctata.

Bougainvillea brittanica.

Turris pileata.

Pleurobrachia pileus.

Sagitta bipunctata.

Tomopteris helgolandica.

Aurelia aurita Lam.

Last year records were given of the food of Aurelia, showing that the ephyra and young metamorphosed medusæ could eat young fishes. The older stages from over 30 mm. across when caught alive were always empty, except for very small plankton organisms, such as are caught in the medium and coarse tow-nets. It is thus possible that the larger food, such as fish, is only taken in the younger stages (see Lebour, 1922, p. 652). In the paper referred to a young Aurelia was kept alive in the plunger jar, and was still living in April, 1922. After this it continued to eat fishes, but an unfortunate accident, when the plunger was broken,

cut off one of its long lips. Although this was regenerated the medusa did not grow, and in July it died. At this time it measured 25 mm., and it grew no larger. During May and June several young Pollack, from 15 to 20 mm. long, were caught and partly eaten, also during the month of July one to three pipe-fishes (*Syngnathus acus*, ca 25 mm. long) a day were taken, until nearly the end of the month when the medusa died.

Planulæ were taken in May, 1922, from the lips of an adult Aurelia, and introduced into a plunger jar. In September several scyphistomæ were seen to be growing on the plunger. These fed on miscellaneous plankton—copepods, decapod larvæ, larval mollusks, and, more rarely, on young fishes (Cottus). They have not as yet, however (July, 1923), budded off any ephyræ.

In 1923, February to March, young ephyræ from tow-netting taken in the Sound were reared up to about 20 mm. across, and fed freely on young fishes and other plankton. After metamorphosis their tentacles were very long and were used in the ordinary way to catch food. As they grew older the tentacles were shorter in comparison with the umbrella.

On April 4th, 1923, a very large number of young Aurelia from about 20 mm. to 25 mm. across were taken in the Young Fish Trawl from between the Victualling Yard and E. Rubble Buoy; 250 were examined for food with the following results :—

206 empty.

13	contained	1 crab zoëa.
8	,,	2 ,,
4	,,	3 ,,
2	,,	4 ,,
1	,,	1 Crab zoëa, 1 Harpacticid.
1	,,	1 egg capsule of Littorina littorea.
1	,,	1 Galathea larva.
1	,,	1 Cirripede Nauplius.
3	,,	1 Acartia Clausi.
1	,,	1 Centropages typicus.
1	,,	1 Rathkea octopunctata.
3	,,	1 Phialidium sp.
3	,,	1 terebellid larva.
2	,,	1 young flat fish.

Crab zoëæ were here the commonest food.

On April 27th a large number of cirripede nauplii were put into the plunger jar with the young Aurelia. These congregated in crowds towards the light and were eaten largely by the Aurelia, which caught them chiefly with their long lips. The lips are armed with tentacles and stinging cells.

Further records of the food of the ephyræ from the tow-nets are as follows :—

Inner Grounds. 1921–1922, *March*, Crab zoëa in 2, Crab zoëa and Sagitta in 1, young Herring in 1, young Clupeoid indet. in 1, Sagitta in 1. *April*, Crab zoëa in 2.

Aurelia, therefore, can eat fishes from its earliest stages up to at least 30 mm. Larger specimens of about 60 mm. have been kept in the plunger jars with fishes, and have not eaten them, and no fishes have as yet been found in those over 30 mm. At all stages they can take the smaller plankton organisms, using ciliary currents (Orton, 1922 ; Gemmill, 1921 ; Percival, 1923), and, at any rate in the younger stages, also catch food by means of their tentacles, lappets, or lips of manubrium. We have as yet no evidence of larger food being taken by the adult.

Chrysaora isosceles (L.).

(Fig. 1)

Last year ephyræ of Chrysaora were recorded which ate young fishes. In May, 1923, a young medusa of this species was brought in from the Sound. It measured ca 25 mm. across, and was in the 8-tentacled stage, the rudiments only of the secondary tentacles being present. The tentacles and lappets that contained the sense organs were a bright chestnut brown ; otherwise the medusa was colourless. This was placed in a plunger jar, and fed upon miscellaneous plankton. It would eat young fishes (newly hatched Cottus, Blennius, Lepidogaster, and Gobius), medusæ (Phialidium, Cosmetira, Saphenia, Obelia, but not Turris), Pleurobrachia, Sagitta, Tomopteris, and occasionally crustacea (copepods, larval decapods). Its chief food seemed to be Cœlenterates and Sagitta, although it always took the small fishes when present. All these it would catch one by one with great rapidity with its tentacles, which at first would be greatly extended to their utmost capacity, so as to be many times the diameter of the umbrella. As the food was caught the tentacles contracted and the lips swept off the food, which was collected in a temporary bag made by the lips below the stomach. Sometimes the food reached the stomach, sometimes not, and, as it was usually wholly or partly digested, it is possible that the digestive juices may be poured out on to it. Later, June 6th, another individual, ca 60 mm. across, also from the Sound, was introduced into the same plunger jar. These

two never attacked one another, although they would eat almost any other medusæ. Two Aurelia, ca 55 mm. across, were put in and were both eaten by the larger Chrysaora; later two more of the same size and a few smaller were also eaten. Some Pollack (ca 25 mm.), Gunnel

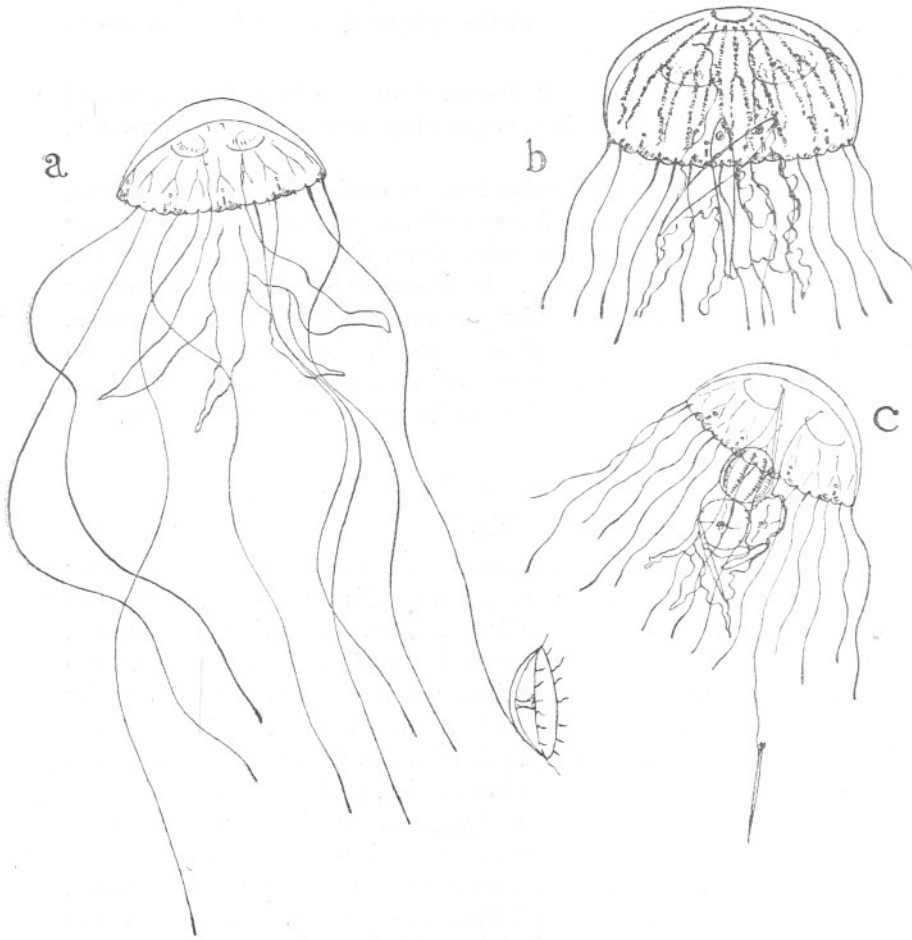

FIG. 1.—Young *Chrysaora isosceles* feeding in plunger jar.
(*a*) 25 mm. across, catching a Phialidium.
(*b*) ca. 60 mm. across, with 2 Pollack inside.
(*c*) The same as (*a*), but older, catching a Sagitta and containing Sagitta, Phialidium and Pleurobrachia, June, 1923.

(ca 35 mm.), Gasterosteus (ca 30 mm.), Rockling (ca 25–35 mm.) were caught by both the Chrysaora. These sometimes reached the stomach and were completely digested, more rarely, however, they were enclosed in a temporary bag made by the lips and were apparently

partially digested, for parts of them were usually ejected. Sometimes as many as four of these larger fishes were taken at one time and caught within a few minutes of one another. At a slightly larger size these fishes were not eaten. Two Rocklings are now in the jar with the larger Chrysaora (July), having been there over a month. These seem to have reached the scaly stage, which may be a deterrent to the medusa.

It is very interesting to watch the medusa feeding rapidly, catching one animal after another until a large pouchful is collected. The tentacles are then contracted for a time whilst digestion goes on. Miss Delap describes the feeding process very accurately (1901). In the Plymouth specimen it was noted that when Crab zoëæ and megalopæ were abundantly present, with medusæ, Pleurobrachia and Sagitta, the three last were immediately eaten and the others left, although if only the crustacea were present a few were eaten, but never so abundantly as the Cœlenterates, Sagitta, and fishes. There is certainly selection here, as is also shown in the way they will not eat one another. Chrysaora is thus an omnivorous feeder, eating chiefly Cœlenterates and Sagitta, but also eating small fishes when available, at any rate in the young stages. Miss Delap's experiences with the same species agree with ours in that medusæ and Pleurobrachia were the favourite food and Sagitta was also frequently taken, but differ in the fact that hers would not eat fishes. The probable explanation is that these were not small or young enough, as a large number of newly hatched and very young fishes were eaten by ours. Moreover, her Chrysaora ephyræ in the process of metamorphosis ate their neighbours of the same species, contrary to our experience with those slightly older. Miss Delap notes that *Turris pileata* was refused as food, a fact that was also observed with the Plymouth specimens.

One record from the tow-nets, *Inner Grounds, April*, 1922, shows a specimen of a young form undergoing metamorphosis containing one Crab zoëa and one Hybocodon.

ÆQUOREA sp.

(Fig. 2.)

On July 7th, 1922, two young Æquorea, measuring ca 32 mm. across, were brought in from the Sound and placed in a plunger jar. One, after eating many Pleurobrachia, young Lepadogaster and newly hatched blennies (*Blennius pholis*), was eaten on July 29th by a young Portunus. The other lived until September, usually feeding voraciously and growing to about 40 mm. across. They caught their food in the usual way with their long tentacles, which in a specimen of ca 30 mm. across would be extended to about 180 mm. The neighbouring tentacles and the

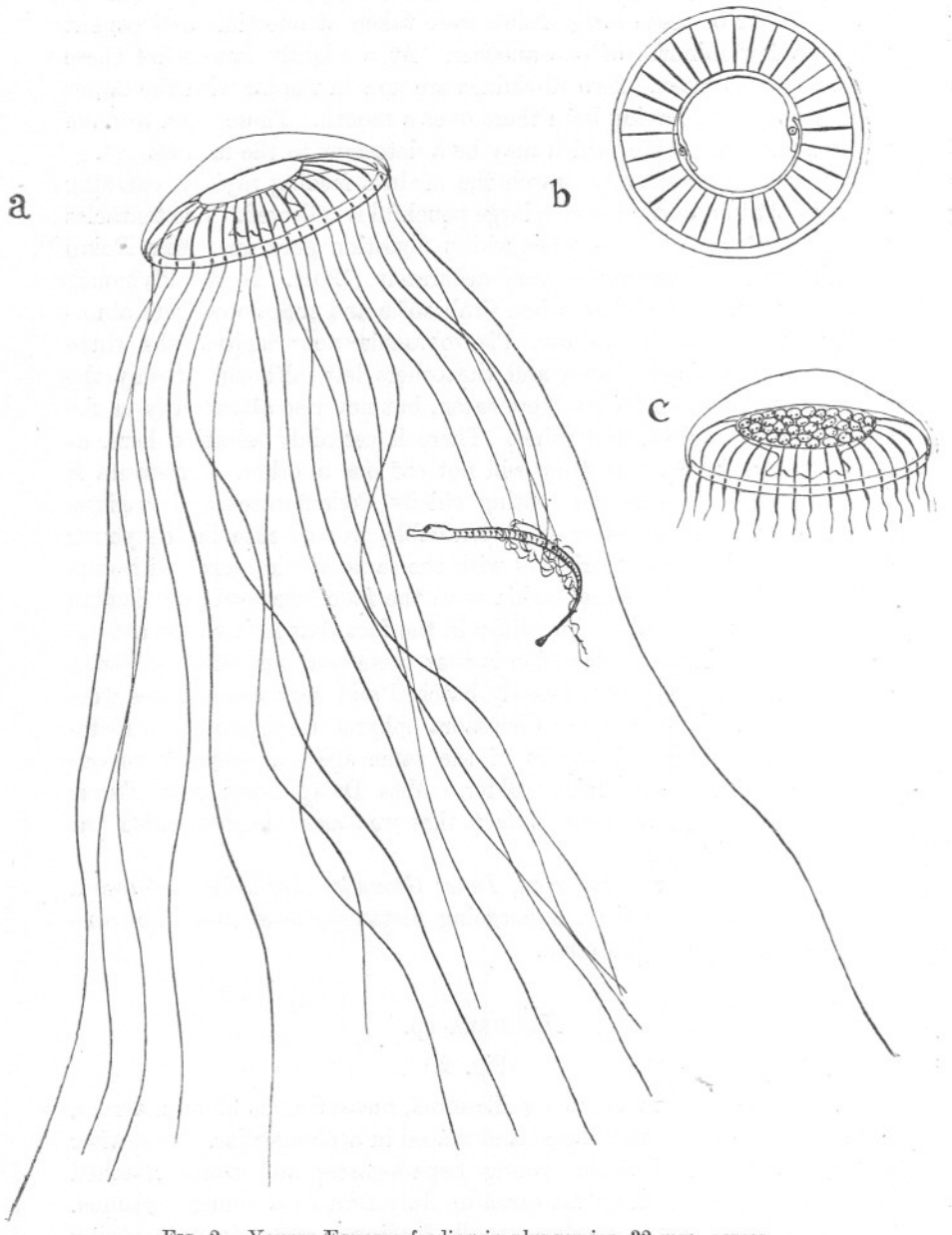

FIG. 2.—Young Æquorea feeding in plunger jar, 32 mm. across.
(*a*) Catching a pipe-fish.
(*b*) With 2 pipe-fishes inside stomach.
(*c*) With stomach full of blennies, July–August, 1922.

edge of the umbrella would help the food into the mouth, and it would then be digested in the stomach. A peculiarly neat arrangement of two pipe-fishes in the stomach is shown in Fig. 2, b. In c the stomach is full of blennies, and the tentacles retracted whilst digestion is going on.

From July to September this medusa ate Pleurobrachia, young Lepadogaster, many young blennies, and several pipe-fishes, these last (Siphon-

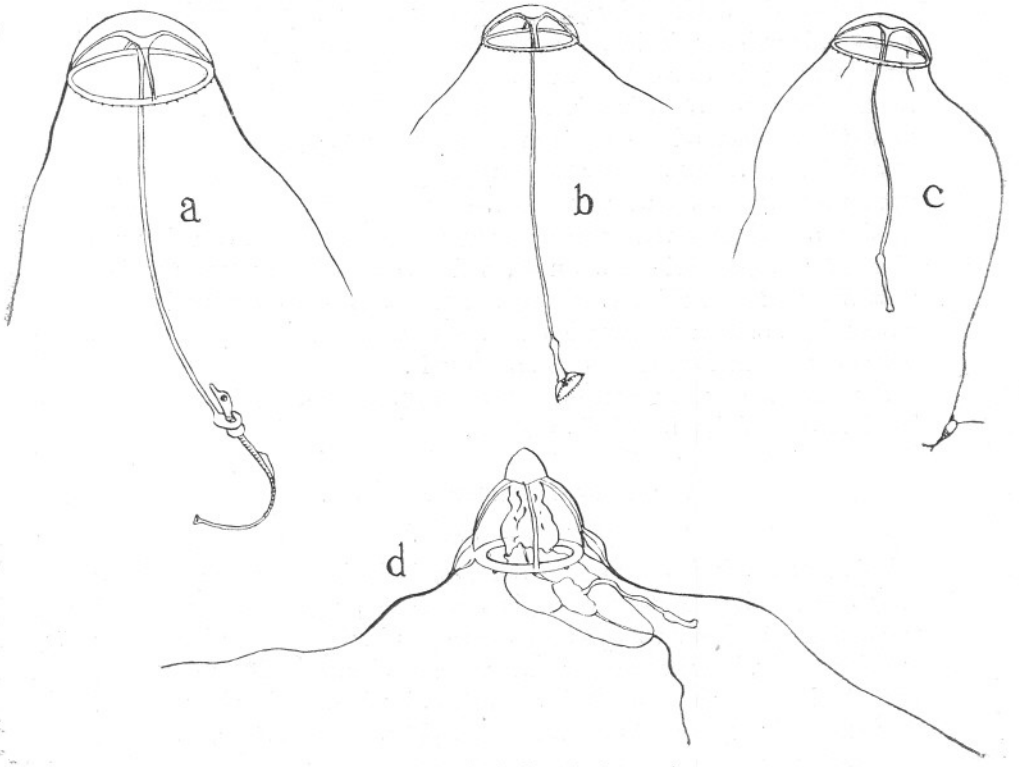

FIG. 3.—(*a*) to (*c*) *Saphenia gracilis* feeding in plunger jar.
(*a*) 19 mm. across, catching a pipe-fish with its manubrium, 12.7.22.
(*b*) 12·5 mm. across, catching an Obelia with its manubrium, 31.7.22.
(*c*) 12·5 mm. across, catching a copepod with its tentacle.
(*d*) *Stomotoca dinema*, 3·5 mm. across, eating Saphenia, 12.7.22.

ostoma, ca 25 mm. long) were eaten during almost the whole of August, from one to three a day, usually two. A Palæmon larva was once taken. On August 8th at 9.30 a.m. a young Portunus bit a piece out of the umbrella; the medusa appeared nearly dead, but at 4.30 revived and ate a pipe-fish. The next day the umbrella was regenerated and the medusa as well as ever.

Mixed plankton was put in the jar as well as the fishes, but the latter were always eaten before anything else, and they were caught with great ease.

Saphenia gracilis.

(Fig. 3, a to c.)

A Gebia larva was recorded last year in a Saphenia. In the summer of 1922 these medusæ were fairly common in the tow-nets, and several were kept alive in the plunger jars. None lived more than a few days, but were active and healthy for that time, and were seen to catch various planktonic animals, including a pipe-fish. The latter, however, after a lengthy struggle escaped. One was caught with a Sagitta inside and another captured a Sagitta in a finger bowl. It was most interesting to watch the method of capture of the food, for Saphenia uses either its manubrium or a tentacle for this purpose. Both of these are armed with similar nematocysts of a long oval shape ; those on the manubrium being smaller and shorter than those on the tentacles. When catching the pipe-fish the manubrium was used, and was so twisted round the fish that a very firm hold was effected. An Obelia was caught with the manubrium, and another specimen was seen to catch a copepod with its tentacle, transfer it to the mouth, and eat it.

A record from the tow-nets, *Inner Grounds, July*, 1922, shows one specimen containing an Obelia medusa.

Cosmetira pilosella Hartlaub.

(Fig. 4, a and b.)

This medusa feeds on various animals, including fishes. Last year Crab zoëæ, Caligus, Autolytus, Sagitta, and Lepadogaster were recorded from it. In 1922 several specimens were put in the plunger jar during June and July, but they are not easy to keep alive, and do not live long, possibly because they are delicate and easily injured in the tow-net. On June 29th, one, ca 10 mm. across, caught a young Cottus, ca 6 mm. long, and ate it. One, ca 15 mm. across, caught and ate a Pleurobrachia, ca 7 mm., and the same specimen also caught a young Labrus whilst the Pleurobrachia was in its mouth. When waiting for food the tentacles are widely outstretched, and soon retracted when the food is caught.

Records from the tow-nets, 1922, are as follows :—

Inner Grounds, June. Pleurobrachia in many, young Callionymus in 1. *Outer Grounds, October.* Sagitta in 1.

Phialidium sp. (chiefly *P. hemisphericum* Gron.).

Last year's records show Phialidium to be a miscellaneous feeder, eating small fishes to a certain extent. Those in the plunger jars continued to eat young fishes when these were present.

The following are records from the tow-nets :—

1922–1923, *Inner Grounds*. *January*, Sagitta in 2. *February*, Sprat egg in 1, Oikopleura in 1. *March*, young Clupeoids in 6, Onos eggs in 2, Oikopleura and Pseudocalanus in 1, Rathkea in 1, Sagitta in 1. *April*, Sagitta in 5, young Clupeoid in 3, larval Gebia in 2, Centropages typicus in 1, Crab zoëa in 2, Crab zoëa and Rathkea in 3, Pseudocalanus in 1,

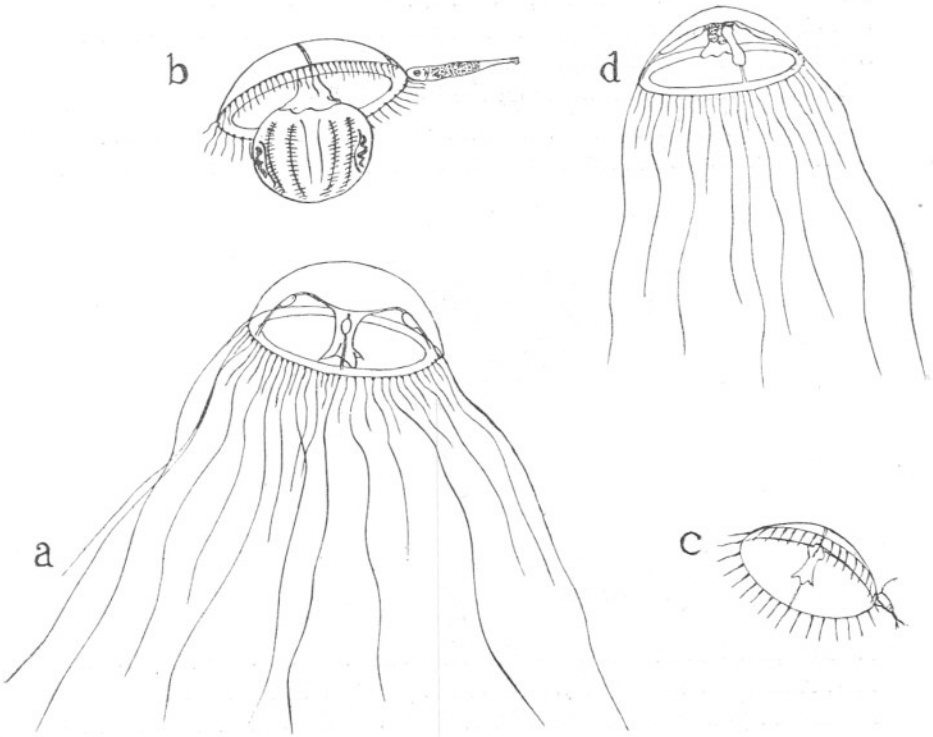

FIG. 4.—(*a*) and (*b*) *Cosmetira pilosella*, ca. 15 mm. across, in plunger jar, 29.6.22.
(*a*) Ready to feed.
(*b*) Eating a Pleurobrachia and catching a young Labrus.
(*c*) Obelia medusa, ca 4 mm., in plunger jar, catching a copepod.
(*d*) *Laodicea undulata*, ca 10 mm. across, plunger jar full of young blennies, 29.7.22.

Calanus in 1. *June*, Calanus in 1, Sagitta in 5, Copepod indet. in 1, Crustacea larvæ in 1, young Cottus in 3, several Pseudocalanus in 1, Obelia medusa in 2, Saphenia in 1. *September*, Sagitta in many. *October*, Sagitta in several. *November*, Sagitta in a few. *December*, Sagitta in a few.

Outer Grounds. *January*, Sagitta in 5. *March*, young Herring in 2, Porcellana larva in 1, Oikopleura in 2. *April*, Sagitta in 1, young Labrus

in 1. *June*, Sagitta in several, Crab zoëa in 2, Calanus in 4. *August*, Sagitta in 2. *November*, Sagitta in 1.

As before Sagitta is the most frequent food, but young fishes, Crustacea, and other Cœlenterates are also taken.

OBELIA sp. (chiefly *O. geniculata* Allman).

Many Obelia were kept alive in a plunger jar, but only once was one seen to catch food. This one, ca 4 mm. across, caught a copepod with one of its tentacles (Fig. 4, c). The tentacles are not very contractile, and hardly stretch out at all.

The following records are from the tow-nets :—

1922–1923, *Inner Grounds*. *March*, Oikopleura in 2, young Whiting in 1. *April*, Acartia in 2, young Clupeoid in 1, Hybocodon in 1, Sagitta in

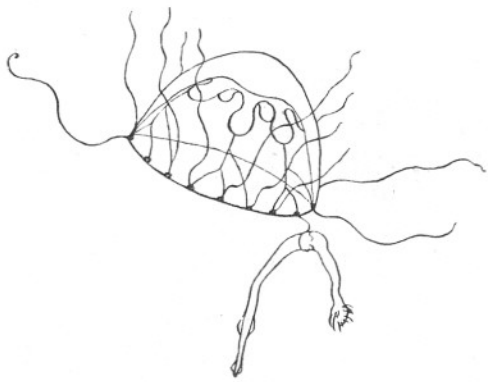

FIG. 5.—*Willsia Stellata*, ca 4 mm. across, catching a Sagitta, plunger jar, 12.10.22.

1. *May*, Sagitta in many, Pseudocalanus in 1, Acartia in 3, Gebia larva in 1, Annelid larva in 1, Crab zoëa in 1, young Whiting in 1, Oikopleura in several, young Callionymus in 1, Obelia medusa in 1, Calanus in 1. *July*, young Callionymus in 2, Pseudocalanus in 1, Calanus in 1. *October*, Sagitta in several, Crab zoëa in 1. *November*, Sagitta in 1. *December*, Pseudocolanus in a few.

Outer Grounds. *April*, Sagitta in 1. *May*, Sagitta in many, Oikopleura in several. *October*, Sagitta in 1, Crab zoëa in 1.

Again the records show Obelia to be a miscellaneous feeder, feeding much on Sagitta and small crustacea, and occasionally on young fishes.

LAODICEA UNDULATA Forbes & Goodsir.

(=*L. cruciata* A. Ag.)

Many last year had eaten Calanus. One (ca 10 mm. across), July 29, 1922, was kept alive for one day only in a plunger jar. It caught and ate

several young blennies, *Blennius pholis*, catching them quickly one after the other with its outstretched tentacles, until the stomach was full (Fig. 4, d).

Willsia stellata Forbes.

This is rare in the tow-nets. One specimen (ca 4 mm. across) placed in the plunger jar, caught and ate a Sagitta (Fig. 5).

Rathkea octopunctata Hæckel.

(Fig. 6.)

Although these medusæ were difficult to keep alive in the plunger jars and were never seen to feed there, they were often taken from the tow-nets whilst feeding, or would feed when freshly brought in and placed in a glass bowl. Small fishes were frequently seen inside them, especially Herring and Sprat. These were usually partly digested and well inside the mouth. In one case, however (Fig. 6, a), a specimen, ca 1 mm. across, had caught a Herring many times its own size, and, as this was much too big to get into the mouth, it was sucking at it, clinging on firmly by its labial tentacles, which are armed with tufts of nematocysts. The stream of fluid food could be seen running up the mouth and stomach and down the canals. In another (Fig. 6, b), which had medusa buds on the manubrium, one of the buds, less than 1 mm. across, had caught a young Sprat with its lips, and in another a Sprat was sticking out of the mouth half digested (Fig. 6, c). Similar instances could be multiplied. Often the bell was completely everted whilst feeding. A specimen taken alive from the tow-net and placed in a glass bowl caught and ate an Oikopleura in this way. The whole animal was finally taken in by a succession of gulps (Fig. 6, d).

The following are records from the tow-nets :—

1922–1923, *Inner Grounds*. *January*, Sagitta in 1. *February*, Crab zoëa in 1, Crab egg in 1, Oikopleura in 3, Copepods in 2, young Sprat in 2, young Herring in 1. *March*, young Clupeoids in 4, 2 Pseudocalanus in 1, Sagitta in 3, Oikopleura in 1. *April*, young Clupeoid in 1, Phialidium in 1, Crab zoëa in 3, copepods indet. in many, larval Gebia in 1. *May*, Pseudocalanus in 3, young Clupeoid in 1, Gebia larva in 1, Acartia in 1.

Outer Grounds, March. Oikopleura in 2, young Clupeoid in 1, Sagitta in 1, Oikopleura in 1.

These records show that fishes are frequently taken, although Crustacea and Sagitta are the commonest food.

BOUGAINVILLEA BRITTANICA Forbes.

This medusa was difficult to keep alive, although it lived in the plunger jar a few days and fed on copepods. A very young specimen, ca 1 mm.

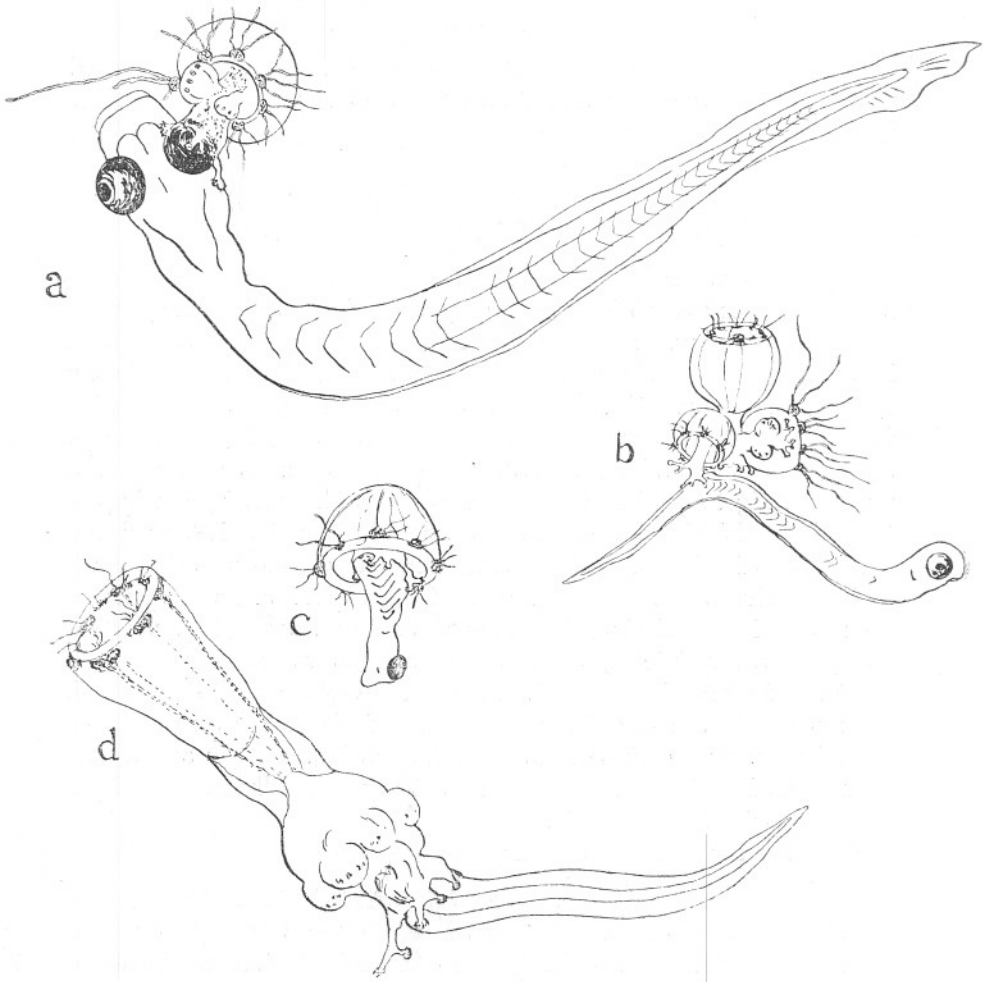

FIG. 6.—*Rathkea octopunctata*, up to 1 mm. across, feeding on Sprat and Oikopleura, Tow-nets, 22.2.23.

(*a*) Eating Herring.
(*b*) Eating Sprat.
(*c*) Sprat half digested.
(*d*) Specimen everted, eating Oikopleura.

across, was taken from the tow-net, having caught a young Sand-eel, *Ammodytes tobianus*, which it was holding in its mouth with its lips tightly clinging to it (Fig. 7).

The following records are from the tow-nets :—

1922, *Inner Grounds. February*, Young Ammodytes in 1. *August*, Podon in 1. *November*, Temora in 1.

TURRIS PILEATA (Forskål).

Records were given last year of the food of this species in the plunger jar. It is omnivorous and highly voracious, often swallowing food much larger than itself. It is a dangerous species to keep in an Aquarium, as it will eat almost anything and apparently is not much eaten by other animals. Two specimens kindly given me by Mr. Clark contained young Whiting longer than the medusa itself. These are engulfed whole, stretching the stomach wall considerably (Fig. 8). One from the Young Fish Trawl, Station 26, lat. 50° 06′ N., long. 4° 20′ W., 27.6.22, had eaten a Whiting, 25 mm. long, which almost completely filled its body (Fig. 8) ;

FIG. 8.—*Turris pileata*, 25 mm. long, containing young Whiting, Y.F.T., Station L6, 27.6.22.

FIG. 7.—*Bougainvillea britannica*, ca 1 mm. across, eating a young Sand-eel, Tow-net, Rame–Eddystone, 12.2.23.

the other from Station L4, lat. 50° 15′ N., long. 4° 13′ W., 9.6.22, in a similar way contained a Whiting 17 mm. long.

The following records are from the tow-nets :—

1922, *Inner Grounds*, *August*. Many Calanus in 5, Acartia in 1, Crab zoëa and Calanus in several, Crab zoëa in 3, Porcellana larvæ in 1.

Outer Grounds. *May*, Young Callionymus in 1. *June*, Calanus in several, young Cottus in 1. *July*, Crab zoëa in several, Calanus in 1, Porcellana larva in 1, Crab zoëa and Porcellana larva in 1. *August*, Calanus in 3, many Crab zoëæ and Calanus in 1, Gebia larva in 1, Anomalocera, Crab zoëa, and Gebia larva in 1, Crab zoëa, Podon, Poecilochætus larva in 1. *November*, decapod larvæ and Calanus in 1.

Stomotoca dinema L. Ag.

In July–August, 1922, a few were kept alive for several days, but only once was one seen to feed when a specimen, ca 3·5 mm. across, ate a Saphenia, ca 7 mm. across (Fig. 3, d). The two tentacles were greatly extended and used for balancing whilst it was eating.

One from the tow-nets contained an Obelia medusa. Last year's records show medusæ, Calanus, and Sagitta as food. No fishes have been seen in it.

Sarsia tubulosa (Sars) and S. prolifera Forbes. *Sarsia tubulosa* was shown last year to feed on copepods, and previously Mr. E. T. Browne had reared it on these. *S. prolifera* in October contained Corycæus in 1, Harpacticid and Acartia in 1. The genus thus appears to be mainly a copepod feeder. No fishes have been seen in them.

Steenstrupia rubra Forbes.

Several medusæ kept alive in the plunger jar caught and ate copepods. These were caught by the long tentacle and transferred to the mouth. It was never seen to eat fishes, but previous tow-net records show fish eggs as food and a Clupeoid and Ammodyte is recorded in the following list of food from the tow-nets :—

1922, *Inner Grounds*. *March*, Young Ammodytes in 2, Calanus in 1, Crab zoëa in 1, Pseudocalanus in 1. *April*, young Clupeoid in 1, copepods in 1. *May*, copepods indet. in 1, Pseudocalanus and Acartia in many, Calanus in several, Temora in 1, Pseudocalanus in 1.

Outer Grounds, *April*. Pseudocalanus in several, Sagitta in 1, egg indet. in 1.

CTENOPHORA.

Pleurobrachia pileus (Fab.).

Pleurobrachia is known to eat young fishes amongst the large variety of food which it takes. Several were kept alive in the plunger jars from June to August, 1922, ranging from 3 mm. to 10 mm. long.

These ate other Pleurobrachia, Calanus, pipe-fishes (Syngnathus, ca 25 mm. long), and Sagitta. In one case a Pleurobrachia, ca 10 mm. long, caught a pipe-fish, ca 25 mm. long. After playing it for half an hour the fish escaped, carrying most of the tentacle with it (Fig. 9). The heads of the pipe-fishes eaten are usually ejected. A Pleurobrachia,

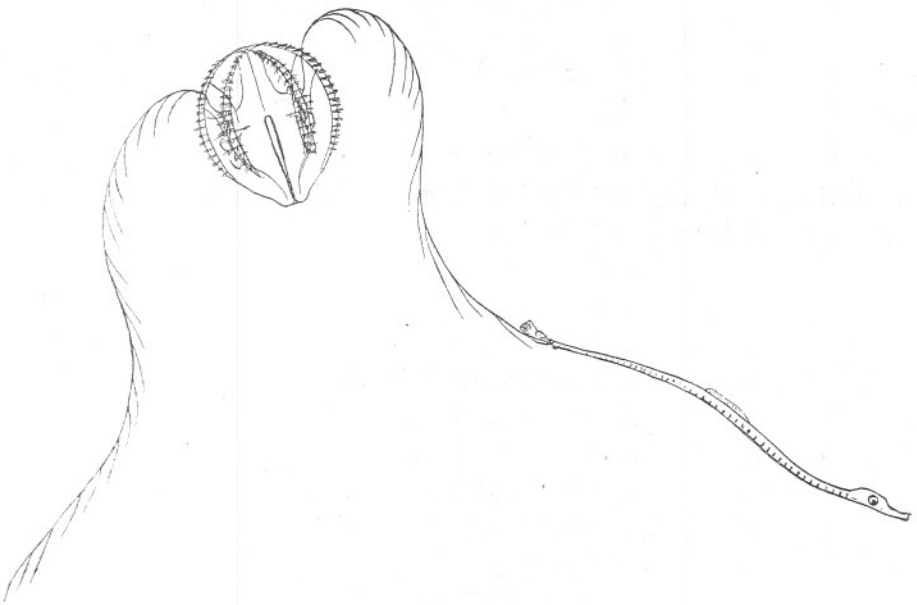

Fig. 9.—*Pleurobrachia pileus*, ca 10 mm., catching a pipe-fish, plunger jar, 29.6.22.

ca 4 mm. long, caught and partly digested a *Gobius Ruthensparri*, over 10 mm. long, which it could not get entirely into its mouth.

When strong and well the Pleurobrachia has its tentacles with the pinnæ fully outstretched and catches the food as it passes by, immediate reaction taking place at the touch of the prey, which is entangled in the contracted tentacle and conveyed to the mouth and stomach.

Mr. Clark has kindly given me specimens from the *George Bligh* cruise in the eastern part of the Channel, January, 1923, where they were very large, ca 18 mm. long. Some of these had eaten Plaice eggs and young Plaice. Others were full of young Herring, newly hatched or only

a few days old. In these cases the mouth and stomach were enormously extended, the aperture being nearly half the diameter of the body (Fig. 10). The following are the records :—

George Bligh cruise, LIII, 1923.

27.1.23, Station 3, lat. 51° 15′ N., long. 1° 51′ E., surface, 1 p.m.
Several Pleurobrachia containing Plaice eggs.

27.1.23, Station 5, lat. 51° 5′ N., long. 1° 51′ E., bottom 30 f., 8 p.m.
Large Pleurobrachia (18–20 mm.).
3 containing Plaice eggs (2 in 1, 1 in 2).
2 ,, 1 Herring and much indiscriminate remains.
1 ,, 2 ,, ,, ,, ,,
1 ,, several Herring.
1 ,, 1 mysid.
1 ,, 1 ,, 1 sagitta.

27.1.23, Station 6, lat. 51° 15′ N., long. 1° 51′ E., surface, 11 p.m.
2 containing at least 4 Herring.
1 ,, ,, 5 ,,
3 ,, ,, 3 ,,
1 ,, ,, 1 ,,
1 ,, ,, 1 and several Sagitta.
1 ,, ,, 2 ,, ,,
1 ,, ,, 3 2 ,,
1 ,, ,, 4 Sagitta, 1 Cumacean.
1 ,, ,, 1 Herring, 1 P. urobrachia.
1 ,, ,, 9 Sagitta.
1 ,, ,, 2 larval Plaice.

27.1.23, Station 6, bottom, 20 f., 11 p.m.
1 containing 1 Euphausiid.
1 ,, skin of ,,
1 ,, Temora, Oikopleura.
1 ,, larval Herring.
3 ,, copepods.
3 ,, Plaice eggs.

29.1.23, Station 12, lat. 49° 5′ N., long 0° 10′ E., bottom, 12.5 a.m.
Many Pleurobrachia containing Herring larvæ. It is interesting that these records are chiefly at night or early morning.

The following records are from the tow-nets :—

1922, *Inner Grounds. June*, Remains of young fish indet. in 2, Sagitta in 1. *July*, young Labrus in 1, young Cottus in 2, Crab zoëa in 1, Gebia larva in 1, Pseudocalanus in 1. *August*, Centropages in 1.

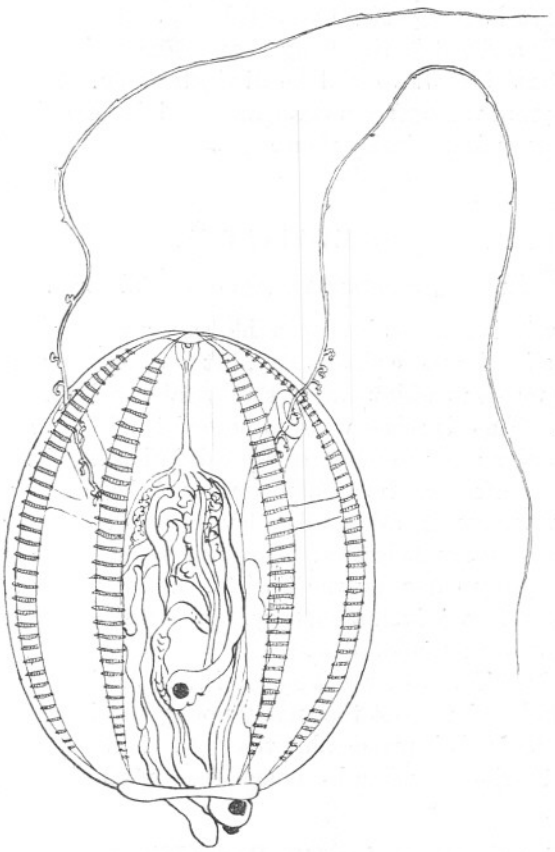

FIG. 10.—*Pleurobrachia pileus*, 18 mm. long, full of young Herring, Y.F.T., *George Bligh*, Voyage LIII, Station 6, 11 p.m., preserved in formalin, 27.1.23.

Outer Grounds, June. Gebia larva in 2, Calanus in 1, Crab zoëa in 1, Sagitta in 1, Bipinnaria in 1, young fish indet. in 1.

BEROË CUCUMIS Fab.

Beroë was taken several times in 1922 with Bolina and Pleurobrachia. It was often seen to be full of either one or the other or both. Sometimes Calanus was seen inside it. This agrees with last year's records. Mr.

Percival, of Leeds University, tells me that last spring, off Robin Hood's Bay on the Yorkshire coast, a number of Beroë taken contained diatoms, probably Coscinodiscus.

Bolina infundibulum Fab.

Two or three large tow-net hauls of Bolina were brought in during June and July and put in the plunger jars. Some of these were young, and their lateral tentacles could be distinctly seen. They lived some time, keeping near the surface and apparently living on minute life there. Nothing was ever found inside them.

CHÆTOGNATHA.

Sagitta bipunctata (Quoy & Gaimard).

Unfortunately it has not been possible as yet to keep Sagitta in the plunger jars alive for more than a day. It was, however, taken several times in the tow-nets whilst eating the larval Herrings, and preserved immediately. These it seizes with its powerful jaws at any part of the body, and usually gets the whole of the fish inside it (Fig. 11). Sagitta is a miscellaneous feeder. Its usual food most of the year being copepods, other Sagitta and young fishes. The latter seem to be specially taken in January and early February, when the young Herring are newly hatched and freely eaten by the Sagitta. A large proportion of the specimens taken in any haul are empty, but so many are eating Herring that much damage must be done.

In some of the hauls of the Young Fish Trawl in the *George Bligh* cruise Mr. Clark pointed out that many young Herring were cut in two or beheaded and this is presumably the work of Sagitta. Many Sagitta were eating Herrings in these hauls and these were kindly given to me by Mr. Clark.

The following records are from the *George Bligh* cruise, LIII, January, 1923 :—

28.1.23, Station 7, lat. 50° 31′ N., long. 0° 48′ E., surface, 5 a.m.
Many Herring beheaded, probably by Sagitta.

29.1.23, Station 12, lat. 49° 50′ N., long. 0° 10′ E., bottom, 19 f., 1.30 a.m.

Many Sagitta eating Herring larvæ.

30.1.23, Station 18, lat. 50° 00′ N., long. 1° 25′ W., surface, 3.30 a.m.

Several Sagitta eating Herring larvæ, some grasping them, some with the larvæ inside.

30.1.23, Station 18, lat. 50° 14′ N., long. 2° 7′ W., bottom, 27 f., 11.50 a.m. Several Sagitta eating Herring larvæ.

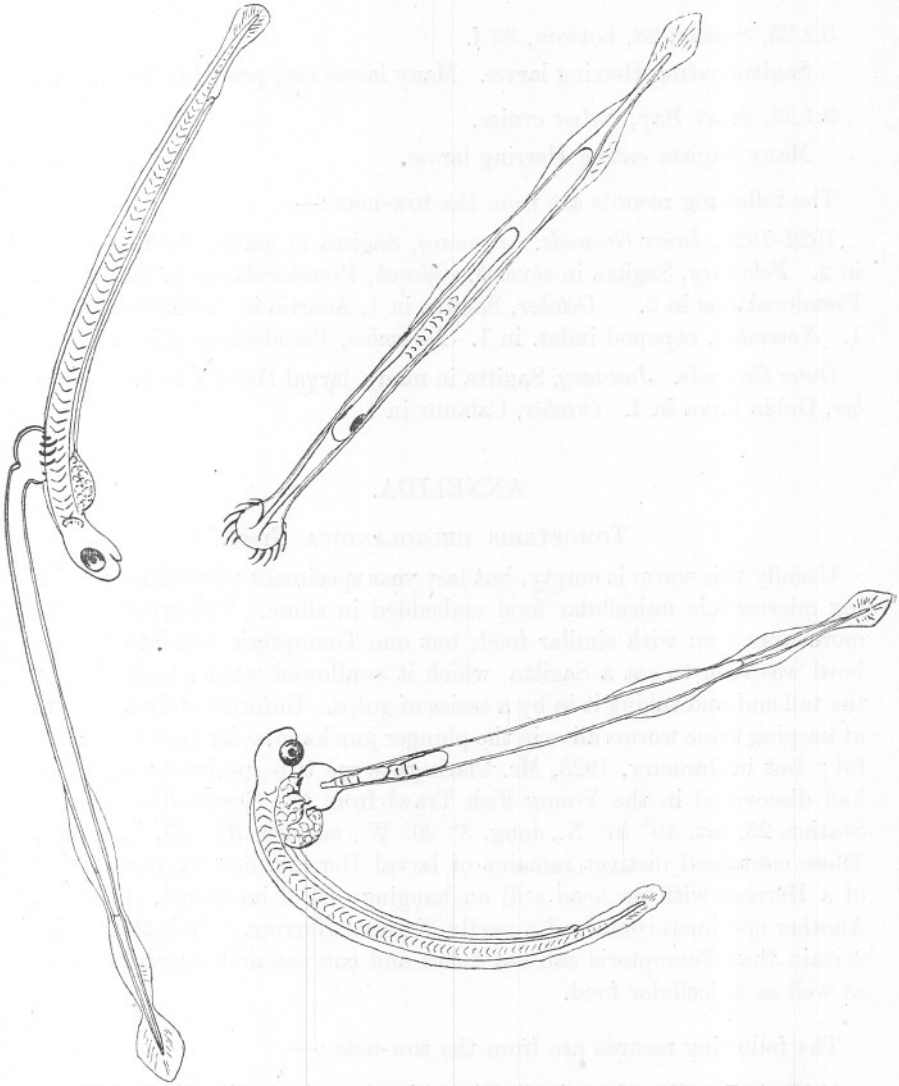

FIG. 11. *Sagitta bipunctata*, eating young Herring, 6·5–7 mm. long, Tow-nets, Start Bay, January, 1923.

31.1.23 Station 25, lat. 49° 51′ N., long. 2° 58′ W., surface, 7.45 a.m. Several Sagitta eating Herring larvæ.

31.1.23, Station 25, bottom, 39 f. Several Sagitta eating Herring larvæ.

5.2.23, Station 28, lat. 50°, 1′ N., long. 1° 48′ W., surface, 8.40 p.m.

Sagitta eating Herring larvæ (about 6 with food out of several hundred).

5.2.23, Station 28, bottom, 33 f.

Sagitta eating Herring larvæ. Many larvæ cut, probably by Sagitta.

9.1.23, Start Bay, *Salpa* cruise.

Many Sagitta eating Herring larvæ.

The following records are from the tow-nets :—

1922–1923, *Inner Grounds*. *January*, Sagitta in many, Pseudocalanus in 2. *February*, Sagitta in several. *March*, Pseudocalanus in 14. *April*, Pseudocalanus in 2. *October*, Sagitta in 1, Acartia in 2, Centropages in 1. *November*, copepod indet. in 1. *December*, Pseudocalanus in a few.

Outer Grounds. *January*, Sagitta in many, larval Herring in 1. *September*, Gebia larva in 1. *October*, Calanus in 1.

ANNELIDA.

Tomopteris helgolandica Greef.

Usually this worm is empty, but last year specimens were seen containing microscopic unicellular food embedded in slime. This year several more were seen with similar food, but one Tomopteris put into a glass bowl was seen to eat a Sagitta, which it swallowed whole, beginning at the tail end and taking it in by a series of gulps. Unfortunately attempts at keeping these worms alive in the plunger jars have so far been unsuccess ful ; but in January, 1923, Mr. Clark gave me two specimens which he had discovered in the Young Fish Trawl from the *George Bligh* cruise, Station 25, lat. 49° 51′ N., long. 3° 20′ W., surface, 31.1.23, 7.30 a.m. These contained distinct remains of larval Herring, one having a third of a Herring with its head still on hanging out of its mouth (Fig. 12). Another specimen contained a partly digested Herring. It is thus quite certain that Tomopteris can eat fishes and can eat and digest Metazoa as well as unicellular food.

The following records are from the tow-nets :—

1922, *Inner Grounds*. *April*, Nitzschia closterium, N. seriata, Thalassiothrix nitzschioides, Paralia sulcata, Chætoceros sp., Streptotheca thamensis in 1. *July*, eggs, indet., much Skeletonema, Nitzschia closterium in 1. *September*, Sagitta in 1. *October*, green flagellates in 1.

Outer Grounds, November. Bits of diatoms, Nitzschia, and others in 1. Many Tomopteris from the tow-nets were empty.

These notes on the larger plankton organisms give us a good idea of their method of feeding and their food in general. All these extremely

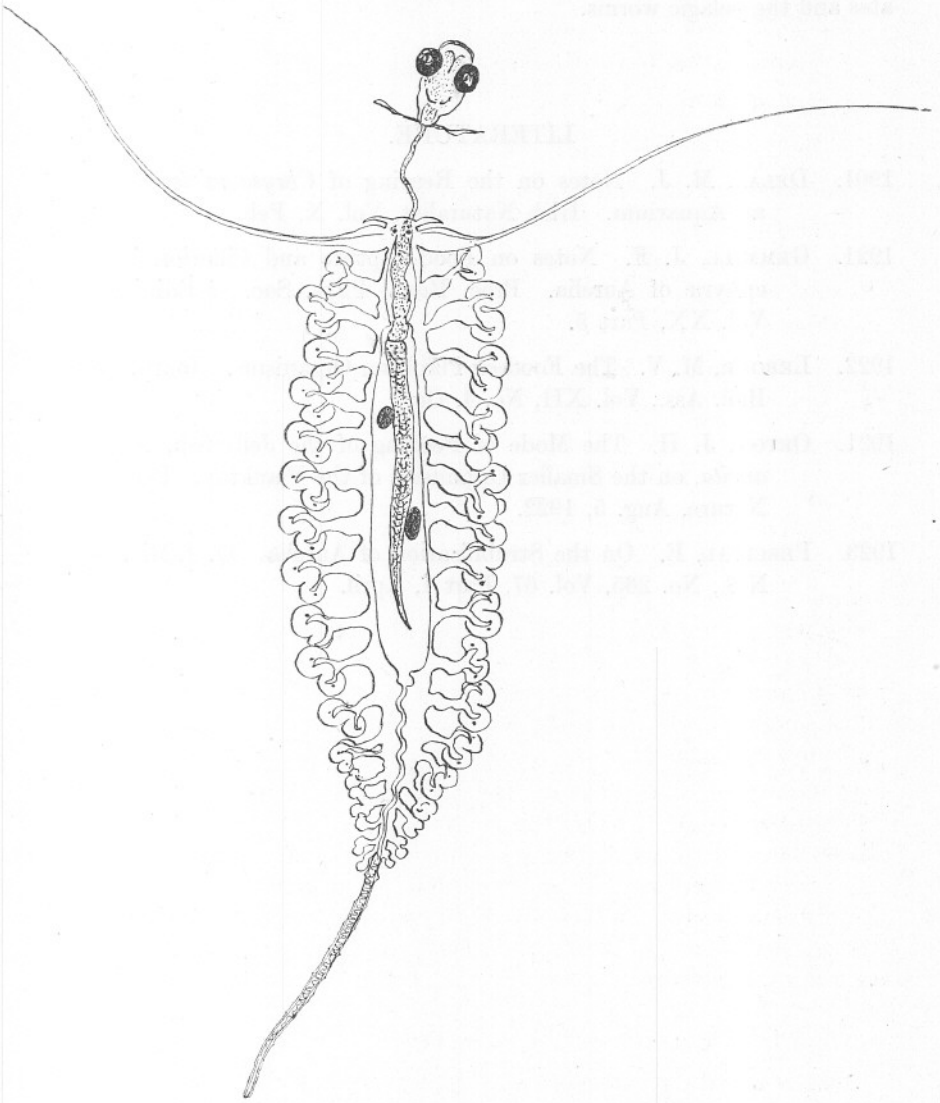

FIG. 12.—*Tomopteris helgolandica*, containing larval Herrings, Y.F.T., *George Bligh*. One Herring is hanging out of the mouth, the second is represented by 2 eyes and part of the body inside.

transparent and delicate creatures are very voracious, and in those regions where the plankton is thickly distributed the animals are con-

tinually preying upon one another. Newly hatched and very young fishes can have little chance against all these enemies, for, as is shown, they must form part of the natural food of most of the common Cœlenterates and the pelagic worms.

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The Hydrogen Ion Concentration of Sea Water in its Relation to Photosynthetic Changes.

Part II.

By

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Head of the Department of General Physiology at the Plymouth Laboratory.

With Figures 1–12 in the Text.

CONTENTS.

INTRODUCTION.

IN the first publication under the above general title * the seasonal changes in sea water were studied, but as explained previously it was not possible to regard all the data as of an equal degree of accuracy. For this and other reasons the seasonal changes were further traced in the hydrographical cruises up to October, 1922, when the approach of the winter equilibrium made it profitless for some months to continue. Since, however, at times from April to September the changes are relatively rapid it may be advisable to follow up the matter during the period mentioned at shorter intervals.

* Journ. Mar. Biol. Assoc., Vol. XII, No. 4, p. 717, 1922.

The precise positions of the stations are recorded, and shown on a map, in the first paper (1922), but it may be said that L 1 is in Plymouth Sound, below the Laboratory, L 2 at the Breakwater, L 3 at Rame Head on the line to the Eddystone, which is L 5, L 4 being intermediate. From that onwards L 6, E 1 and E 2 are on the course to Ushant, which is near E 3. The stations N 1, N 2, N 4 and N 5 lie between Ushant and Cork Harbour, N 3 lies between the Scillies and Cornwall, and E 6 is further north in the Bristol Channel. E 7, a station which is now usually omitted, lies S.E. from the Wolf Light off the Lizard. Stations N 4 and N 5 were worked by the Irish boat.

THE COLORIMETRIC METHOD OF DETERMINING HYDROGEN ION CONCENTRATIONS.

The determinations were made in hard glass test tubes of 12 mm. internal diameter. The tubes were graded so that their external diameters did not vary by more than $\pm 0{\cdot}5$ mm. The water was examined immediately after it was drawn, and 10·0 c.c. measured from a pipette was added in each case to 0·50 c.c. of indicator. The tops of the tubes were closed by rubber caps. Before comparison it is necessary to allow the freshly drawn water to reach the same temperature as the standard tubes in the cabin. If this is not done the colder sea water in winter appears more alkaline than in reality it is. It must be emphasized that sufficient accuracy is not obtained by adding drops of indicator from a pipette or dropping bottle. The motion of the ship usually makes it impossible to keep the tube vertical, accordingly measurements were invariably made with a pipette of the first quality divided into 0·01 c.c. These pipettes are 145–187 mm. in length for 1·00 c.c., so with the tip against the side of the test tube it is thought that 0·50 c.c. can be measured to $\pm 0{\cdot}005$ c.c., namely, that the meniscus is within approximately one millimetre of the 0·50 position.

The indicator used was mainly cresol red, 0·02 per cent. In the presence of a little toluene as preservative the standard tubes with this indicator have undergone no perceptible change since mixed on November 8th, 1921, a period of twenty months. It may be added that portions of the standard buffer at pH8·14 to which cresol red was added on November 8th, 1921, and February 28th, 1922, were indistinguishable when first compared and are still so. When not in use the tubes are kept in the dark as a precaution. It was intended to use this set throughout the year, but as the bottle of indicator was spilled during a storm the supply failed. A fresh dilution of cresol red was made on March 28th, and standard tubes with it were in use up to the end of the work in October. The

measuring out of the buffer solution anew is necessary for each fresh dilution of indicator, so it is advisable to make up a supply sufficient to last through the work contemplated.

The standards were the borax, boric acid, sodium chloride mixtures of McClendon (1917), corrected for the chloride normality of the sea water off Plymouth. The standards were at pH7·99, 8·04, 8·09, 8·14, 8·16, 8·19, 8·24, 8·29. For estuarine water a small correction was applied as previously mentioned. In addition to these standards the tubes in a depth series and from station to station were compared with each other, a further aid to uniformity being thus obtained.

For the more alkaline samples, pH8·24 and upwards, thymol blue was used as well as cresol red, since the latter is nearing the end of its range, taking into account that pH0·18 has to be taken off for salt error. Thymol blue is a serviceable indicator, and sealed tubes containing it were used for work in the Pacific by Mayor (1922) for two years without appreciable change. When the solution is sterile and access of carbon dioxide is prevented tubes with thymol blue have been found by the writer to be quite satisfactory, but in the alkaline range where this indicator is serviceable traces of carbonic acid, whether of endogenous or exogenous origin, have a marked effect.

Xylenol blue (*p*-xylenol sulphonephthalein) introduced by A. Cohen (1922) has also been tried. Its acid range is given as pH1·2–2·8, the same as that of thymol blue, and its alkaline range as pH8·0 (yellow) to 9·6 (blue) as against pH8·2–9·8 for thymol blue. When compared for two months with thymol blue no change could be noticed in solutions at pH8·24 and 8·29 ; moreover, the distinction between pairs of tubes at pH0·05 interval was appreciably greater with xylenol blue in 0·02 per cent concentration than with an equal volume of 0·04 per cent thymol blue. In Clark and Lubs' buffer solutions xylenol blue gives a grey blue at pH8·6 and a good blue at pH9·0, whereas thymol blue is yellowish blue at pH8·6 and light slaty blue at pH9·0. There are thus, with xylenol blue, very easily observed changes in a region of importance in the study of photosynthesis, and the overlap with cresol red is rather better than is the case of thymol blue. For the region over pH9 the latter is the more satisfactory.

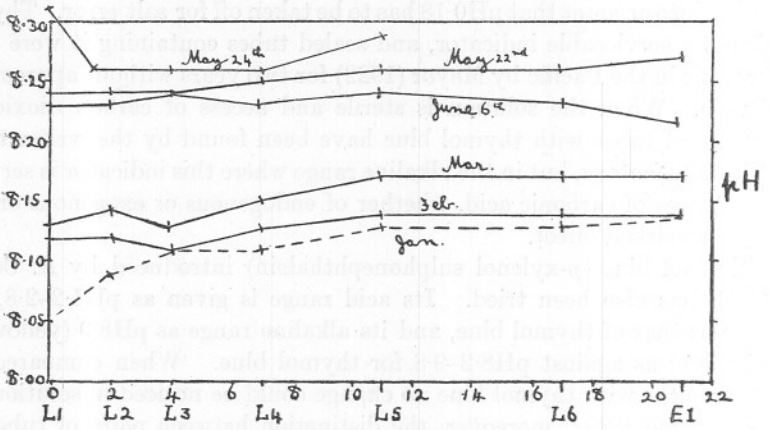
The indicators used by Palitzsch and again recommended by him (1922), namely, *α*-naphtholphthalein and phenolphthalein, were tried and rejected on account of their lack of permanence of colour, which necessitates the mixing of fresh standards each day. Neutral red is also recommended by Palitzsch for use between pH6·5–7·8. It has the disadvantage that it precipitates slowly in the more alkaline region, for which reason phenol red is to be preferred. Thymolphthalein, tetra-brom phenolphthalein, *α*-naphthol sulphonephthalein and cresolphthalein

were also tried and found to be less satisfactory than the sulphonephthaleins previously mentioned, though cresol phthalein gives a more stable solution than the other phthaleins tested.

THE RELATION OF THE WATER OF PLYMOUTH SOUND TO THAT OF THE OPEN SEA THROUGHOUT THE YEAR.

The observations of hydrogen ion concentration, temperature and salinity recorded in Part I were continued up to October, 1922, and the results for the L series of stations are given in the following tables, the pH values being corrected for salt error. Figure 1 shows the pH values

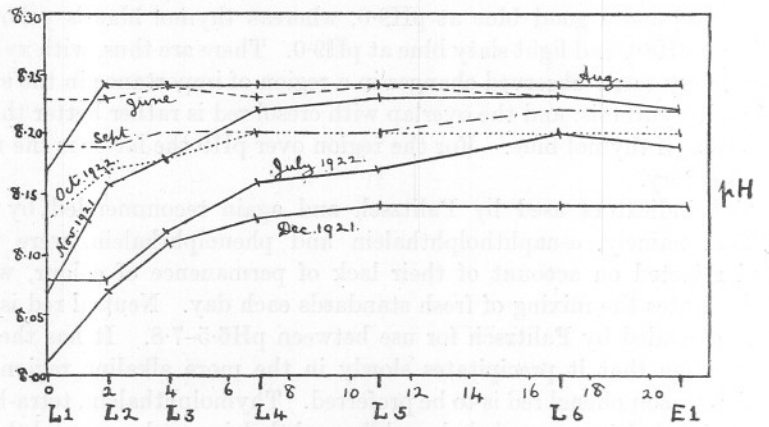
SEASONAL CHANGES IN pH, SURFACE.



Miles from Station L 1.

FIG. 1.

SEASONAL CHANGES IN pH, SURFACE.



Miles from Station L 1.

FIG. 2.

from L 1 to E 1. It may be seen that from January onwards to May the water is increasing in alkalinity, and whereas the surface water of the open sea is more alkaline than that of the Sound in winter, in May there is little difference, or a slight advantage in favour of the Sound. For June the values are somewhat lower than in the end of May. A comparison of the values for May 22nd, 24th, and June 6th leads one to the conclusion that the calmness of the sea and consequent undisturbed state of the surface layers is an important factor, since the more alkaline water produced by the intense photosynthesis in the surface layers is not mixed up with the deeper water. Figure 2 shows the June values again, by comparison with which a great fall is noticeable early in July. August shows high values, thereafter a slow fall takes place to the winter conditions of December and January. The value for November, 1921, seems abnormally high, consequent upon the exceptionally hot and sunny weather experienced that autumn.

	May 22nd, 1922.			June 6th.		
Station.	t °C.	pH.	s °/$_{oo}$.	t °C.	pH.	s °/$_{oo}$.
L 1	14·4	8·24	31·62*	13·8	8·23	34·09*
L 2	13·0	8·24	33·27	13·3	8·23	34·59
L 3	12·9	8·24	34·34	12·6	8·24	35·16
L 4	12·9	8·25	34·62	12·8	8·23	35·24
L 5	12·3	8·26	35·15	12·8	8·24	35·26
L 6	12·6	8·26	35·14*	12·8	8·23	35·29*

	July 11th.			August 3rd.		
Station.	t °C.	pH.	s °/$_{oo}$.	t °C.	pH.	s °/$_{oo}$.
L 1	13·8	8·08	33·49	14·6	8·18	34·37
L 2	13·9	8·08	33·80	13·8	8·24	35·22
L 3	14·1	8·12	34·89	14·3	8·24	35·24
L 4	15·3	8·16	35·26	14·2	8·24	35·29
L 5	14·0	8·17	35·37	14·3	8·24	35·30
L 6	14·1	8·20	35·33	14·5	8·24	35·29

	September 22nd.			October 12th.		
Station.	t °C.	pH.	s °/$_{oo}$.	t °C.	pH.	s °/$_{oo}$.
L 1	14·6	8·19	34·79	13·8	8·13	33·03*
L 2	14·5	8·19	35·23	14·1	8·17	34·63
L 3	14·6	8·20	35·23	14·1	8·18	34·83*
L 4	14·4	8·20	35·31	14·2	8·20	35·22
L 5	14·4	8·20	35·32	14·3	8·20	35·33
L 6	14·6	8·22	35·31	14·2	8·20	35·24

* Denotes mean of duplicate titrations.

The seasonal changes at the surface in pH value and in temperature are shown in Fig. 3 for L 1 and L 3, taken as a coastal station, since it lies off Rame Head, and the water bottle may be lowered safely to 45 metres. Thus while not removed from coastal influences the water is fairly deep. The fall in pH value at L 1 in December and July, with the rise in May and September, are clearly brought out. The L 3 values are steadier in December, but the July fall is noticeable, also rises in May and August. It may be observed that while there is a general similarity between the curves for pH and temperature it is obvious that the variations in pH are not purely temperature changes. Under the section dealing with E 1 will be found a figure (Fig. 7) showing the pH values corrected to 12° C., as explained there. The corrected values for L 1 and L 3 are given in the following table :—

	L 1			L 3		
	t °C.	pH.	pH corr. to 12 °C.	t °C.	pH.	pH corr. to 12 °C.
Nov. 9th . .	11·6	8·07	8·07	14·0	8·18	8·16
Dec. 12th . .	10·6	8·01	8·02	11·8	8·11	8·11
Jan. 11th . .	10·0	8·05	8·07	10·3	8·11	8·13
Feb. 6th. . .	8·2	8·12	8·16	8·9	8·11	8·13
March 15th .	8·5	8·12	8·16	8·9	8·13	8·15
March 29th .	8·0	8·12	8·16	8·6	8·14	8·16
May 22nd . .	14·4	8·24	8·22	12·9	8·24	8·23
May 24th . .	13·7	8·31	8·29	14·1	8·26	8·24
June 6th . .	13·8	8·23	8·21	12·6	8·24	8·24
July 11th . .	13·8	8·08	8·06	14·1	8·12	8·10
Aug. 3rd. . .	14·6	8·18	8·15	14·3	8·24	8·22
Sept. 22nd. .	14·6	8·19	8·16	14·6	8·20	8·17
Oct. 12th . .	13·8	8·13	8·11	14·1	8·18	8·16

A few exceptionally high pH values for May 24th, recorded in a later section, include observations on the L series as well as the remainder of a long coastal run. The results are plotted in Figure 1.

The changes in salinity for stations L 1 to L 5 are shown in Figure 4, from August, 1921, to October, 1922. The values for L 6 and E 1 were similar to those for L 5, so are omitted for clearness. The minima in January and in May are noticeable. For the inner stations more frequent readings would be necessary correctly to show the changes. It suffices here to establish the fact that even at L 3, and out to L 4, the disturbing effect of the river water is noticeable.

In viewing any station from a biological standpoint it is of importance to consider the uniformity or otherwise of the conditions from surface to

SEASONAL CHANGES IN TEMPERATURE AND pH AT STATIONS L 1 AND L 3, SURFACE.

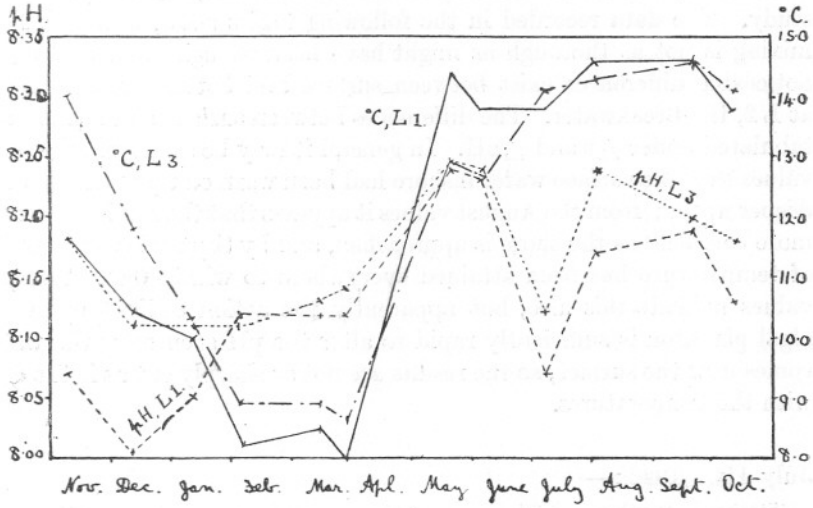


FIG. 3.

SEASONAL CHANGES IN SALINITY, STATIONS L 1 TO L 5, SURFACE.

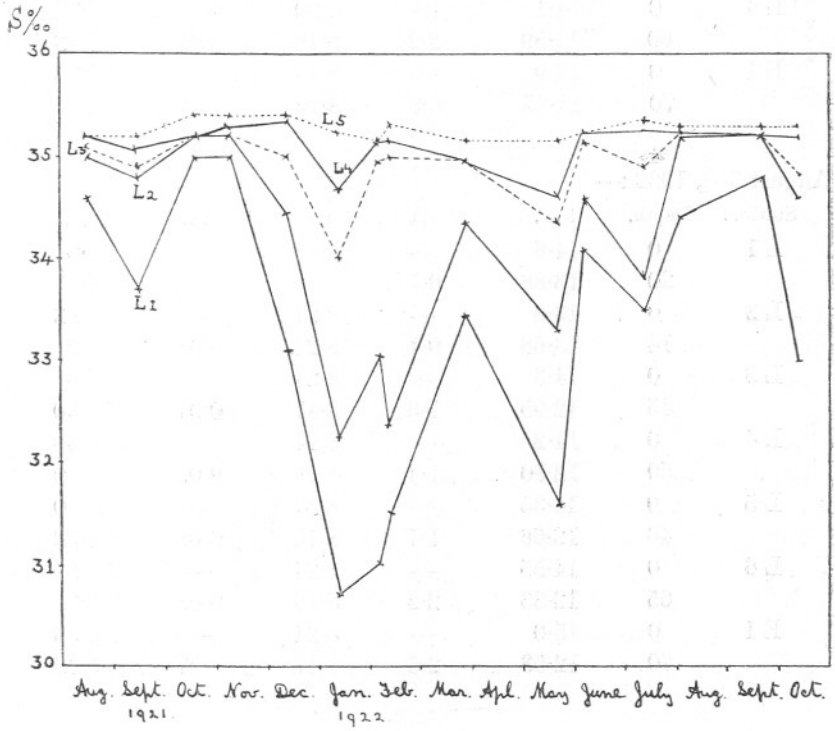


FIG. 4.

bottom. This has been done in detail for the international stations, but in consequence of the shallower water and more thorough mixing at the stations of the L series, economy of effort precluded a similar systematic study. The data recorded in the following tables show, however, that mixing is not as thorough as might have been thought, and that quite noticeable differences exist between surface and bottom water, except at L 2, the Breakwater. The differences between surface and bottom are tabulated under $\triangle$t and $\triangle$pH. In general it may be seen from the July values that the surface water inshore had been warmed up more than the deeper water ; from the August values it appears that the mixing becomes more complete as the shore is approached, and by September uniformity of temperature has been attained everywhere to within 0·4°. The pH values indicate this also, but apparently the action of light upon the algal plankton is sufficiently rapid to alter the pH soon after the water comes near the surface, so the results are not as sharply cut as is the case with the temperatures.

July 11th, 1922 :—

Station.	Depth.	t °C.	△t	pH	△pH	s °/₀₀.
L 5	0	14·0	—	8·17	—	35·37
	50	12·08	1·9	8·16	0·01	35·35
L 6	0	14·1	—	8·20	—	35·33
	60	11·89	2·2	8·16	0·04	35·42
E 1	0	12·9	—	8·19	—	35·38
	70	11·95	0·8	8·16	0·03	35·37

August 3rd, 1922 :—

Station.	Depth.	t °C.	△t	pH	△pH	s °/₀₀.
L 1	0	14·6	—	8·18	—	34·37
	20	13·88	0·7	—	—	35·17
L 2	0	13·8	—	8·24	—	35·22
	14	13·68	0·1	8·21	0·03	35·28
L 3	0	14·3	—	8·24	—	35·24
	45	12·95	1·3	8·17	0·07	35·30
L 4	0	14·2	—	8·24	—	35·29
	50	12·80	1·4	8·16	0·08	35·30
L 5	0	14·35	—	8·24	—	35·30
	46	12·66	1·7	8·16	0·08	35·32
L 6	0	14·55	—	8·24	—	35·29
	65	12·33	2·2	8·16	0·08	35·34
E 1	0	15·0	—	8·24	—	35·32
	70	12·53	2·5	8·17	·07	35·32

September 22nd, 1922 :—

Station.	Depth.	t °C.	△t	pH	△pH	s °/₀₀.
L 1	0	14·6	—	8·19	—	34·79
	20	—	—	—	—	—
L 2	0	14·5	—	8·19	—	35·23
	14	14·4	0·1	8·19	0·00	35·21
L 3	0	14·6	—	8·20	—	35·23
	45	—	—	—	—	—
L 4	0	14·4	—	8·20	—	35·31
	50	—	—	—	—	—
L 5	0	14·4	—	8·20	—	35·32
	46	14·33	0·1	8·20	0·00	35·28
L 6	0	14·6	—	8·22	—	35·31
	65	14·24	0·4	8·18	0·04	35·28
E 1	0	14·4	—	8·22	—	35·30
	70	14·17	0·2	8·18	0·04	35·29

THE SEASONAL CHANGES IN THE HYDROGEN ION CONCENTRATION OF THE OPEN SEA AT VARIOUS STATIONS AND DEPTHS.

The observations were made at E 1 monthly, and at the other stations, weather permitting, during the five annual cruises, February, end of

SEASONAL CHANGES, STATION E 1, SURFACE AND BOTTOM.

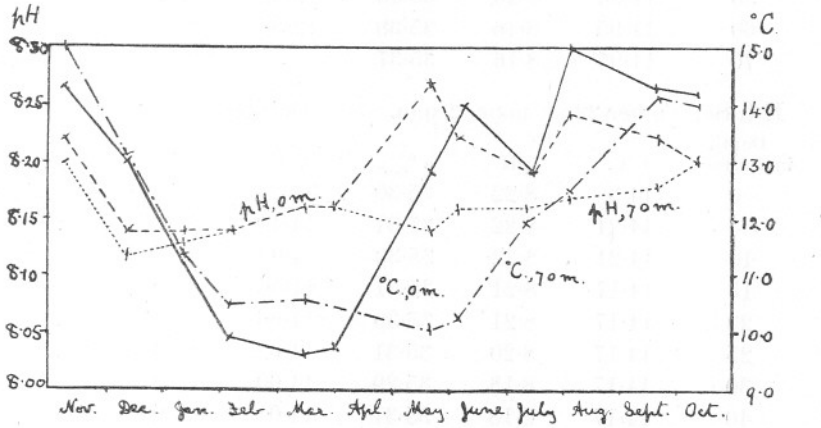


FIG. 5.

March, May, July and November. The continuation of the results for E 1 is shown in the following tables, and these and the former values are plotted in Figures 5, 6, 7 and 8.

E 1, May 22nd, 1922, 1–3 p.m.				June 6th, noon–2 p.m.		
Depth in metres.	t °C.	pH	s °/₀₀.	t °C.	pH	s °/₀₀.
0	12·8	8·27	35·24	13·95	8·22	35·30*
5	12·70	8·27	35·23	13·89	8·22	35·23*
10	12·05	8·27	35·26	13·58	8·21	35·28
15	12·00	8·25	35·26	12·12	8·20	35·28
20	11·28	8·25	35·27*	10·60	8·17	35·25
25	10·50	8·24	35·33	10·41	8·17	35·26*
30	10·25	8·21	35·34	10·41	8·17	35·21
40	10·10	8·16	35·40	10·37	8·17	35·22
50	10·08	—	35·39	10·27	—	35·22
60	10·08	8·14	35·35	10·27	—	35·22
70	10·05	8·14	35·38*	10·27	8·16	35·22

E 1, July 11th, 4–6 p.m.				August 3rd, noon–2 p.m.		
Depth in metres.	t °C.	pH	s °/₀₀.	t °C.	pH	s °/₀₀.
0	12·8	8·19	35·38	15·00	8·24	35·32
5	12·34	8·19	35·35	14·58	8·24	35·32
10	12·08	8·19	35·36	14·58	8·24	35·29
15	12·07	8·19	35·35	14·41	8·23	35·32
20	12·03	8·18	35·35	12·81	8·17	35·29
25	12·00	8·18	35·36	12·45	8·17	35·36
30	12·00	8·17	35·37	12·40	8·17	35·33
40	11·97	8·16	35·38	12·38	8·17	35·35
50	11·96	8·16	35·40	12·38	8·17	35·34
60	11·95	8·16	35·39	12·38	8·17	35·34
70	11·95	8·16	35·37	—	8·17	35·32

E 1, September 22nd, noon–2 p.m.				October 12th, noon–2 p.m.		
Depth in metres.	t °C.	pH	s °/₀₀.	t °C.	pH	s °/₀₀.
0	14·3	8·22	35·30	14·2	8·20	35·31
5	14·21	8·22	35·31	14·10	8·20	35·25
10	14·21	8·22	35·30	14·08	8·20	35·26*
15	14·17	8·21	35·31	14·06	8·20	35·28
20	14·17	8·21	35·30	14·06	8·20	35·28
25	14·17	8·20	35·31	14·02	8·20	35·27
30	14·17	8·18	35·29	14.00	8·20	35·26
40	14·17	8·18	35·31	14·01	8·20	35·25
50	14·17	8·18	35·29	14·00	8·20	35·27*
60	14·17	8·18	35·30	14·02	8·20	35·26
70	14·17	8·18	35·29	14·02	8·20	35·29

* Denotes mean of duplicate titrations

The variations of temperature and pH value from November, 1921, to October, 1922, at both surface and bottom, are displayed in Figure 5. The values all fall in early winter, the temperatures for the bottom being slightly higher than those for the surface from November to March. The surface minimum temperature was noted in the middle of March, the bottom in May, though possibly it may have occurred in April or even late March, since observations are wanting then. The sunny weather of late May led to a rapid warming up of the surface water, which the winds of June mixed with the deeper layers as shown by the approximation of the two temperature curves. The maximum surface temperature was noted in August, and the bottom maximum in September. Then and in October the two were close together.

At no time of the year are the surface pH values below those for the bottom, though during the winter, up to March, the two are almost or absolutely identical. The noticeable feature in the curve is the rapid rise to the maximum late in May, followed by the secondary minimum in July. That this is not due merely to mixing appears to be shown by Figure 8, and the data upon which it is based, as will be explained later. Figure 5, too, shows no marked rise in the pH curve for the bottom during June and July to account for the fall in the surface values. The rise occasioned by photosynthetic removal of carbon dioxide by the algal plankton, which has become abundant by May, is thus seen to be followed by a fall in pH value. For this several factors may in part be responsible, namely: (1) Mixing with deeper water consequent upon rough weather in June; (2) the absorption of atmospheric carbon dioxide tending to restore the equilibrium value; (3) respiration carried on by the algal plankton transported into deeper water with insufficient illumination, and by the plankton fauna increasing both in numbers and size as a result of the abundant algal food supply.

By October the mixing at E 1 has become complete, and the value pH8·20 is back to the figure of the previous November at 70 metres depth. Stormy weather, through addition of carbon dioxide and also apparently a heavy death rate in the plankton, tend to lower the pH value to the winter equilibrium.

In the foregoing discussion the physical effect of alteration in temperature has been temporarily left unconsidered. Pure water changes its hydrogen ion concentration from pH7·00 to pH7·10, as the temperature falls from 22° C. to 16° C., and the change proceeds uniformly for many degrees above and presumably below this range. Such changes are, however, automatically corrected in the colorimetric method by the changes in the standard tubes, provided sufficient time elapses for the samples to reach the temperature of the standards as already mentioned. There is, however, another temperature effect, namely, upon the solu-

bility of carbon dioxide in water and upon the equilibrium between calcium carbonate, bicarbonate and carbonic acid. By boiling, the removal of carbon dioxide results in a continual dissociation of bicarbonate till only carbonate is left, pH10–10·2 resulting for sea water. Conversely on cooling more carbon dioxide goes into solution, and the pH value falls. McClendon (1917) gives the temperature coefficient as pH0·01 added for each rise of 1° C. That the temperature effect is not the only one operative in the case of sea water is evident from Figure 6, in which the pH values and temperatures at 10 metres are plotted. Thus pH8·20 may be found with temperatures from about 10·5–14·5° C., and a temperature of 12° C. may be accompanied by pH8·14–8·25. The 10-metre values were plotted because conditions at that depth are less subject to fluctuations than at the surface, especially fluctuations of temperature.

In the table which follows are given the surface and bottom values at E 1 for temperature and pH, also the latter corrected to 12° C. by

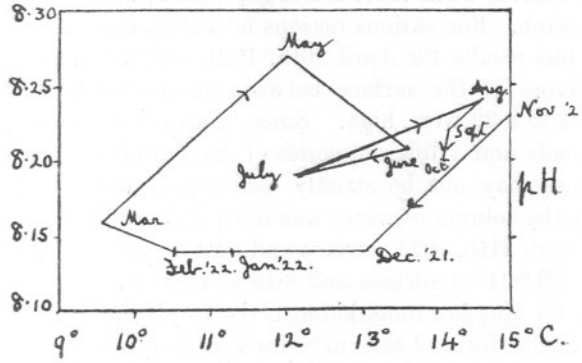
	t °C.	pH	pH corr. to 12 °C.	t °C.	pH	pH corr. to 12 °C.
Nov. 9th .	14·96	8·23	8·20	14·98	8·20	8·17
Dec. 12th .	12·95	8·14	8·13	13·11	8·14	8·13
Jan. 11th .	11·24	8·14	8·15	11·35	8·13	8·14
Feb. 6th .	9·9	8·14	8·16	10·50	8·14	8·15
March 15th	9·6	8·17	8·19	9·62	8·17	8·19
March 29th	9·7	8·16	8·18	—	—	—
May 22nd .	12·8	8·27	8·26	10·05	8·14	8·16
June 6th .	13·95	8·22	8·20	10·27	8·16	8·18
July 11th .	12·8	8·19	8·18	11·95	8·16	8·16
Aug. 3rd .	15·00	8·24	8·21	12·53	8·17	8·17
Sept. 22nd	14·3	8·22	8·20	14·17	8·18	8·16
Oct. 12th .	14·2	8·20	8·18	14·02	8·20	8·18

McClendon's coefficient. This temperature was chosen as entailing, on an average, the minimum amount of correction, the May maximum remaining unaffected, and the December and January values being reduced and increased by pH0·01 respectively. The corrected values are shown graphically in Figure 7, which may be compared with Figures 3 and 5, showing the uncorrected values.

The December minimum is well marked at all three stations, as are also the May and August maxima and the depression in July. The meeting of the surface and 70 metres pH curves in October is noteworthy.

The pH values at various depths at E 1 have been given in Part I and in the tables in this section. The results are shown graphically in Figure 8. The marked fall in pH for the whole column of water from November to

SEASONAL CHANGES, STATION E 1, 10 METRES.



Temperature plotted against pH value.

FIG. 6.

SEASONAL CHANGES IN pH, CORRECTED TO 12 °C.

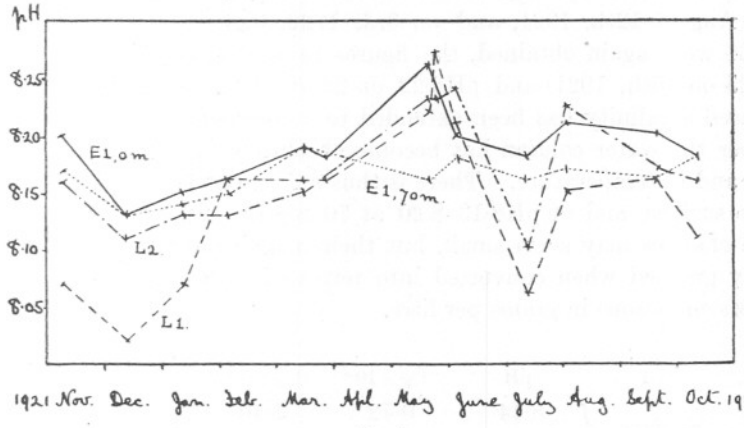


FIG. 7.

SEASONAL CHANGES, STATION E 1, pH VALUES AT VARIOUS DEPTHS.

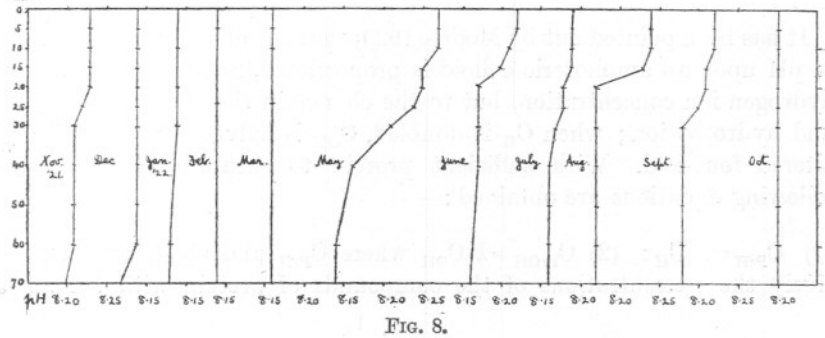


FIG. 8.

December, 1921, is at once evident, as is also the uniformity of the column up to March, when there is a slight shift upwards, namely, to the right in the graph. For various reasons no values could be obtained for April, 1922, but results for April 26th, 1921, only show a difference of pH0·02 in favour of the surface between it and 30–70 metres. The values pH8·24 to 8·22 were high. Since, however, these were the first estimations made and a different series of standard buffers was used, the absolute values may not be strictly comparable with those for 1922. The fact that the column of water was fairly uniform is, however, established. On April 24th, 1923, surface and bottom were at pH8·18 at E 1, E 2 being at pH8·24 on surface and 8·18 at bottom.

The values for May are remarkable, a rise to pH8·21 being found even at 30 metres. The form of the curve for this month is quite unlike that of any other month, the June values being lower and tending towards the summer minimum early in July. As mentioned in detail further on, both in 1921 and 1922, low values for the eastern stations at this time were accompanied by high values for the western.

On August 12th, 1921, and on 3rd, 1922, high values, pH8·27 and pH8·24 were again obtained, the figures remaining high in September, pH8·25 on 15th, 1921, and pH8·22 on 22nd, 1922. By September the increased alkalinity has been extended to a considerable depth, and by October the water column has become absolutely uniform, both in pH value and in temperature. There is thus a range at E 1 of pH8·14–8·27 at the surface, and of pH8·13–8·20 at 70 metres, close to the bottom. These changes may seem small, but their magnitude may be the more readily grasped when converted into terms of hydrogen and hydroxyl ion concentrations in grams per litre.

E 1		pH	$C_H \times 10^{-8}$	$C_{OH} \times 10^{-6}$	Percentage fall in C_H.
Surface		8·14	0·72	1·40	—
		8·27	0·54	1·88	25
Bottom		8·13	0·74	1·37	—
		8·20	0·63	1·60	15

It has been pointed out by Moore (1920) that the effect of an alteration in pH upon an amphoteric colloid is proportional, not to the change in hydrogen ion concentration, but to the change in the ratio of hydrogen and hydroxyl ion; when C_H is doubled, C_{OH} is halved and the ratio is altered four-fold. With sufficient protein to saturate all ions the following equations are obtained:—

(1) $C_{PrH} = k_1 C_H$; (2) $C_{PrOH} = k_2 C_{OH}$ where C_{PrH} and C_{PrOH} are respectively the concentrations of the compounds of protein with the ions.

By division (3) $C_{PrH} / C_{PrOH} = K_1 \frac{C_H}{C_{OH}}$. But for water $C_H \cdot C_{OH} = k_3$, or $C_{OH} = \frac{k_3}{C_H}$, so by substitution in (3) $C_{PrH} / C_{PrOH} = K_1 / k_3 [C_H]^2 = K_2 [C_H]^2$.

Taking the values for the sea at E 1 surface, summer and winter extremes, the C_{PrH} / C_{PrOH} ratio is altered as $100^2 / 75^2$, namely, in ratio 1·00 : 0·56, and for the bottom 1·00 : 0·72.

The results obtained at the other international stations from July, 1921, to July, 1922, inclusive, are given in Part I and in the tables which follow here.

E 2, May 22nd, 8–10 p.m. July 11th, 10 p.m.–midnight.

Depth in metres.	t °C.	pH	s °/₀₀.	t °C.	pH	s °/₀₀.
0	12·5	8·24	35·36	13·9	8·17	35·37
5	12·30	8·24	35·34	12·85	8·17	35·36
10	11·80	8·19	35·29*	12·72	8·17	35·35
15	11·00	8·19	35·32	12·72	8·17	35·35
20	10·92	8·16	35·31	12·70	8·17	35·35
25	10·73	8·16	35·31	12·70	8·17	35·35
30	10·68	8·15	35·34	12·70	8·17	35·35
40	10·62	8·15	35·31	—	—	—
50	10·60	—	35·34*	12·67	8·17	35·37
60	10·60	—	35·33	—	—	—
70	10·62	—	35·35	12·70	—	35·37
85	10·60	8·15	35·36	12·67	8·17	35·34

E 3, May 23rd, 1922, 4–6 a.m. July 12th, 1922, 6–8 a.m.

Depth in metres.	t °C.	pH	s °/₀₀.	t °C.	pH	s °/₀₀.
0	11·9	8·18	35·28*	11·9	8·16	35·31
5	11·40	—	35·29	11·81	8·16	35·31
10	11·20	8·18	35·29	11·81	8·16	35·31
15	—	—	—	11·80	8·16	35·29
20	—	—	—	11·81	8·16	35·34
25	11·02	8·17	35·29	11·81	8·16	35·31
30	—	—	—	11·81	8·16	35·33
50	—	—	—	11·70	8·15	35·32
60	—	—	—	11·65	—	35·33
75	—	—	—	11·65	8·15	35·29
100	11·05	8·16	35·31	11·60	8·15	35·32

* Denotes mean of duplicate titrations.

N 1, May 23rd, noon to 2 p.m.				July 12th, 1–3 p.m.		
Depth in metres.	t °C.	pH	s °/₀₀.	t °C.	pH	s °/₀₀.
0	12·9	8·18	35·29	13·7	8·22	35·26
5	12·46	—	35·29	13·19	8·21	35·26
10	11·58	8·18	35·26	11·83	8·21	35·28
25	11·00	8·17	35·28	11·38	8·17	35·28
75	10·51	—	35·34	10·74	8·14	35·31
100	10·50	8·16	35·33*	10·72	8·14	35·28

N 2, May 23rd, 7–9 p.m.				July 12th, 6–8 p.m.		
Depth in metres.	t °C.	pH	s °/₀₀.	t °C.	pH	s °/₀₀.
0	12·0	8·17	35·15	13·6	8·21	35·26
10	11·30	—	35·18	12·70	8·20	35·25
25	10·4	8·16	35·17	12·48	8·17	35·26
75	10·28	8·15	35·20	—	—	—
85	—	—	—	11·98	8·16	35·26

N 3, May 23rd, midnight.				July 12th, 10 p.m.		
Depth in metres.	t °C.	pH	s °/₀₀.	t °C.	pH	s °/₀₀.
0	12·1	8·19	35·19*	13·0	8·20	35·24
60	10·15	8·16	35·19	—	—	—
70	—	—	—	12·32	8·16	35·21

E 6, May 24th, 3–5 a.m.				July 13th, 1–3 a.m.		
Depth in metres.	t °C.	pH	s °/₀₀.	t °C.	pH	s °/₀₀.
0	12·2	8·19	35·00*	13·3	8·20	35·15
5	11·78	—	35·04	13·40	—	35·12
10	11·08	—	35·08	12·64	—	35·15
15	10·94	—	35·07	12·55	—	35·08
20	10·62	—	35·12	12·52	—	35·09
25	10·20	—	35·11	12·48	—	35·08
30	9·90	—	35·20	11·47	—	35·12
40	9·87	—	35·17	—	—	—
50	9·87	—	35·19	11·32	—	35·24
75	9·87	8·16	35·17	11·28	8·16	35·24

Considering in the first place the surface pH values it may be seen that the two years are similar in July. Furthermore, and this is quite remarkable, the more westerly stations are in each case more alkaline than the

* Denotes mean of duplicate titrations.

easterly. These data, from April 1921, onwards, including values for E 1, are tabulated together under the heading "Surface pH values at international stations."

Surface pH values at international stations :—

	E 1.	E 2.	E 3.	N 1.	N 2.	N 3.	E 6.	E 7.
April, 1921	8·24	—	—	—	—	—	—	—
July	8·17	8·17	8·18	8·22	8·22	—	—	8·25
Aug.	8·27	—	—	—	—	—	—	—
Sept.	8·25	—	—	—	—	—	—	—
Nov.	8·23	8·20	8·20	—	8·14	8·14	8·14	8·13
Dec.	8·14	—	—	—	—	—	—	—
Jan., 1922	8·14	—	—	—	—	—	—	—
Feb.	8·14	—	—	—	—	—	—	—
March	8·16	8·17	8·17	8·16	8·15	8·15	8·14	—
May	8·27	8·24	8·18	8·18	8·17	8·19	8·19	8·21
June	8·22	—	—	—	—	—	—	—
July	8·19	8·17	8·16	8·22	8·21	8·20	8·20	8·20
Aug.	8·24	—	—	—	—	—	—	—
Sept.	8·22	—	—	—	—	—	—	—
Oct.	8·20	—	—	—	—	—	—	—

They are shown graphically in Figure 9, on which values for L 1 are also plotted. Though these figures are plotted in a line from L 1 to E 7 it

SEASONAL CHANGES IN pH VALUE, SURFACE.

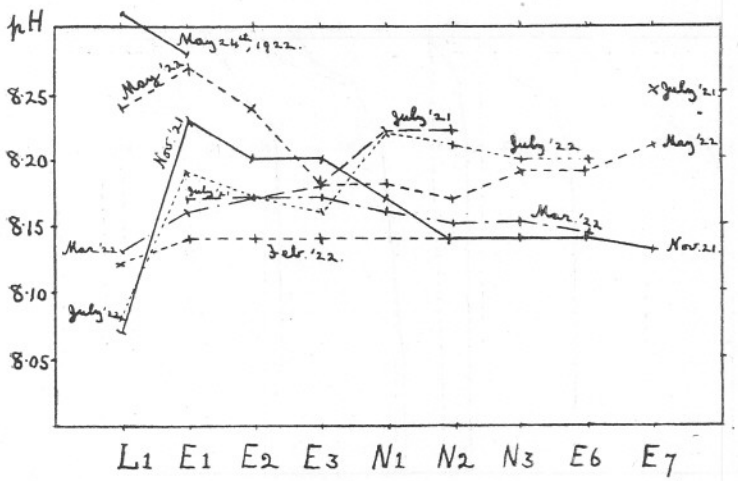


FIG. 9.

CHANGES IN pH WITH DEPTH, MAY, CONTINUOUS LINE AND JULY, DOTTED LINE.

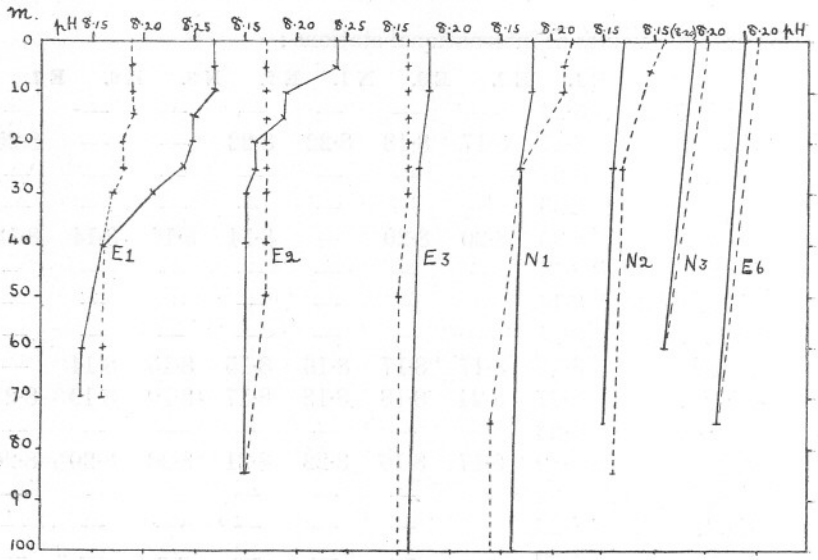


FIG. 10.

CHANGES IN TEMPERATURE WITH DEPTH, MAY, CONTINUOUS LINE AND JULY, DOTTED LINE.

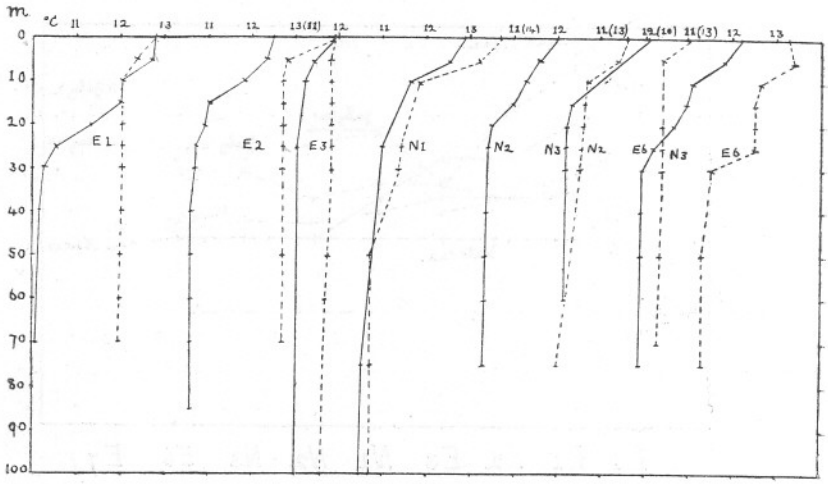


FIG. 11.

must be remembered that the stations form roughly a wide V, with L 1 and E 6 as the N.E. and N.W. apices, with E 3 at the south. E 7 is an extra station off Cornwall. The positions are shown in the map in Part I.

Though the July values are higher at N 1 and N 2 than at E 1 and E 2, yet for the latter the May pH values have the advantage. There is thus some evidence for a lag in the attainment of a high alkalinity as deeper and more open water is reached. The conditions prevailing at the international stations in May and July are rendered clearer by reference to Figures 10 and 11. The former shows the pH values and the latter the temperatures. At E 1 and E 2 the pH values for July are, as previously pointed out, below those for May, whereas the reverse is true in the main for N 1 and N 2. In all cases the temperature is higher in July than in May. The figures obtained for temperature and pH give an indication of the extent to which vertical currents mix the water. The straightening out of the curves for both quantities for E 1 and E 2 point to a better mixing in July than in May. At E 3 mixing is thorough, both then and at other times judging from other temperature records. At N 1, a deep station far from land, mixing is less efficient, whereas it increases at N 2 to N 3, becoming less again at E 6.

In this connection the results obtained by Palitzsch, quoted in Part I should be borne in mind, since they illustrate the penetration of the photosynthetic effect upon pH values to depths at which it seems reasonable to suppose that only mixing with more alkaline water could be the causal agent.

It remains to be considered how far the time of day affects the pH values found and the surface temperatures. There is undoubtedly a warming of the surface in calm sunny weather and an increase in pH value, but as may be seen from the figures in the table on page 112 the pH values do not seem to be appreciably affected, so that the differences from station to station may be considered in the main as real differences.

The figures given on page 112 seem to show that the rise in pH value of the surface water in the course of the day is very small when corrected for temperature by subtracting pH0·01 for each degree rise. The effect of mixing of the water is evident at E 3 as already pointed out, also off the Lizard, where both temperature and pH value are considerably below the values given fairly consistently for the rest of the day. The L 2 values, and the L 3 to some extent on 24th indicate mixing.

Comment may be made on the record for 1.30 a.m., May 24th, in this table. Shortly before this hour the *Salpa* entered a shoal of fish, which darted away from the bows by the hundred, each fish leaving a streak of phosphorescence. There was nothing abnormal in the water sample taken in the shoal. Steaming about nine knots there was no diminution in the numbers of fish by 2 a.m., when plankton tow-nets

were lowered for twenty minutes. This involved going dead slow, and the nets gave an abundance of copepods, but no fish scales, which strengthens the supposition that the fish were mackerel. On resuming the normal rate of steaming the fish showed no decrease for about a

Locality.	Date.	Hour.	T°C.	pH.	Notes.
L 1	May 22nd	10.45 a.m.	14·4	8·24	One hour flood tide.
L 2	,,	11 a.m.	13·0	8·24	
L 3	,,	—	12·9	8·24	
L 4	,,	—	12·9	8·25	
L 5	,,	Noon	12·3	8·26	
L 6	,,	1 p.m.	12·6	8·26	
E 1	,,	1.30 p.m.	12·8	8·27	Day calm and sunny.
E 2	,,	8.15 p.m.	12·5	8·24	
E 3	May 23rd	4 a.m.	11·9	8·18	Mixing of the water.
N 1	,,	Noon	12·9	8·18	Day calm and sunny, morning fog.
N 2	,,	7.15 p.m.	12·0	8·17	
N 3	,,	11.30 p.m.	12·1	8·19	
Half-way between N 3 and E 6	May 24th	1.30 a.m.	12·0	8·19	Fish amazingly abundant.
E 6	,,	3.10 a.m.	12·2	8·19	
Just off W. point of Lizard	,,	10.40 a.m.	11·4	8·21	Mixing of the water.
Mount's Bay, 4 m. E. of Lizard	,,	11.5 a.m.	12·5	8·27	
Off Dodman, 6 miles on E. by N. course, 23 miles from Lizard	,,	1.30 p.m.	13·0	8·28	Day calm and sunny.
From Lizard, 34 miles S.W. of Rame Head, 7 m., 1 m. N.W. of L 5	,,	2.45 p.m.	14·0	8·28	
L 4	,,	3.25 p.m.	14·2	8·29	
L 3	,,	3.50 p.m.	14·6	8·26	
L 2	,,	4.15 p.m.	14·1	8·25	
L 1	,,	4·30 p.m.	13·4	8·25	Mixing of the water.
East slip, below laboratory	June 10th	4.45 p.m.	13·7	8·29	High water.
East of Breakwater	June 12th	3 p.m.	—	8·28	Three hours' flood tide.
		11 a.m.	—	8·22	

quarter of an hour, when they gradually diminished in numbers, so that when E 6 was reached at 3 a.m. a few only were to be seen. The long-continued passage through such numbers of fish was a most remarkable sight.

VARIATION OF HYDROGEN ION CONCENTRATION IN RELATION TO THE MOVEMENT OF FISHES.

As mentioned in Part I the work of Shelford and Powers showed that fishes were able to detect very small changes in hydrogen ion concentration the active migratory fishes being in this respect far more sensitive than those which normally rest on or near the bottom. Powers (1921) also

traced the limits within which various fish were found in Puget Sound and its neighbourhood. Thus herring were only once found in water with a pH above 7·9, and they were never found in water below pH7·71. The greatest number of herring were observed in water at pH7·76–7·73. While such preferences and variations may be observed in estuarine waters, in the sea around this coast, the water is, as demonstrated by the figures already given, very uniform in alkalinity, and during winter not far from pH8·14, yet herring are at times caught in great quantity, as well as other fish. One can only conclude that under such conditions the hydrogen ion concentration of the water can be of no importance in determining the movements of fish. Salinity variations also seem entirely too small to have any significance in this connection. Variation in temperature seems to be the most promising physical factor for correlation with the movements of fish.

SOME FACTORS AFFECTING THE PHOTOSYNTHETIC ACTION OF THE ALGAL PLANKTON.

The balance between photosynthesis and respiration has already been discussed in Part I, and it was pointed out that in the sea light may often be a limiting factor, so that an increase in temperature is unaccompanied by any rise in assimilation. The optimum illumination for one type of alga need not be that for another, and it has been shown by the late Professor B. Moore with Whitley and Webster (1922) that whereas a green alga carried on photosynthesis seven or eight times as actively in sunshine as in a diffuse light, the increase was only five-fold for brown algæ on the average, and for the red the average in the two intensities was the same. Information of this kind, as regards the plankton algæ, is lacking. It has, however, been found by the writer that a pure culture of the diatom *Nitzschia closterium* W. Sm., kindly supplied by Dr. E. J. Allen, may in good north illumination be maintained in a strongly alkaline condition, close to pH9·4. *Ulva latissima* L. in direct sunlight withstood a temperature of 27° C. and brought the reaction of the water to pH9·7. It is not claimed that this denotes a real difference in the power of these algæ to increase the pH value, though it may do so.

The pressure of carbon dioxide must be reduced to a very minute amount at such high pH values. McClendon (1917) has determined the relation of pH and pressure of carbon dioxide, and the following values have been read from his graph. They refer to 20° C., and for lower temperatures pH0·01 should be subtracted for each degree. (See Table, page 114.)

Pressure of carbon dioxide in millimetres of mercury.	pH value at 20° C.	pH at 12° C.
0·10	8·42	8·34
0·14	8·30	8·22
0·16	8·26	8·18
0·19	8·20	8·12
0·21	8·16	8·08
0·25	8·10	8·02

Considering the maximum value for E 1, surface, pH8·27 at 12·8°, this corresponds to 0·13 mm. pressure of carbon dioxide, that for the minimum value, pH8·14 at 9·9° being 0·17 mm. For the bottom the minimum values are practically identical, and when in May the surface water was at pH8·27, the bottom water was at pH8·14 and 10° C., with a pressure of 0·17 mm. Later on in the year, in August, the surface water was at pH8·24 and 15·0°, corresponding to 0·14 mm., here the rise in temperature in part makes up for the lower pH value and helps to keep the pressure low. In October surface and bottom agree in giving pH8·20 at 14°, namely, 0·16 mm.

The extremes for E 1 are therefore seen to be a winter value of 0·17 mm., reduced in spring to 0·13 mm., thereafter increasing to 0·16 in July at at the pH summer minimum and rising later to 0·14 mm. in August and 0·16 in October. Since 0·13 mm. pressure is equivalent to 1·7 parts per ten thousand, and 0·17 mm. to 2·2 of carbon dioxide it is clear that even in winter the sea is capable of absorbing this gas from the air as the normal concentration is slightly over 3·3 parts per ten thousand, corresponding to a pressure of 0·25 millimetres. Direct determinations of the carbon dioxide content of the air over the sea at various seasons would be of interest; for the Pacific, Mayor found a mean value of 3·15 parts.

Since the illumination is the main factor controlling photosynthesis it is of interest to see how the pH value of sea water varies with regard to the sunshine and duration of the day. Accordingly the returns of the Meteorological Office were examined, and the records for the mean number of hours of sunshine per month were found for England, S.W. The results are also expressed as percentages of the total sunshine possible, and from this the average length of the day, from sunrise to sunset, was found for each month. These figures are plotted in Fig. 12, as values for 15th of each month. The pH values, as corrected to 12° C. are also plotted, together with C_{OH} values in order to show the numerical changes in alkalinity corresponding to them. In addition the pressures of carbon dioxide, as found from McClendon's chart for the pH values, are also shown. These are uncorrected for temperature, since an increase in temperature leads to an increase in carbon dioxide concentration which is itself of importance in yielding an ampler supply for photosynthesis.

It is at once evident that there is a close agreement between the maximum of sunshine daily, in May, and the maximum in pH values. The carbon dioxide minimum and the C_{OH} maximum naturally coincide, being derived from the pH values. The duration of the day is, however,

SEASONAL CHANGES AT STATION E 1, SURFACE.

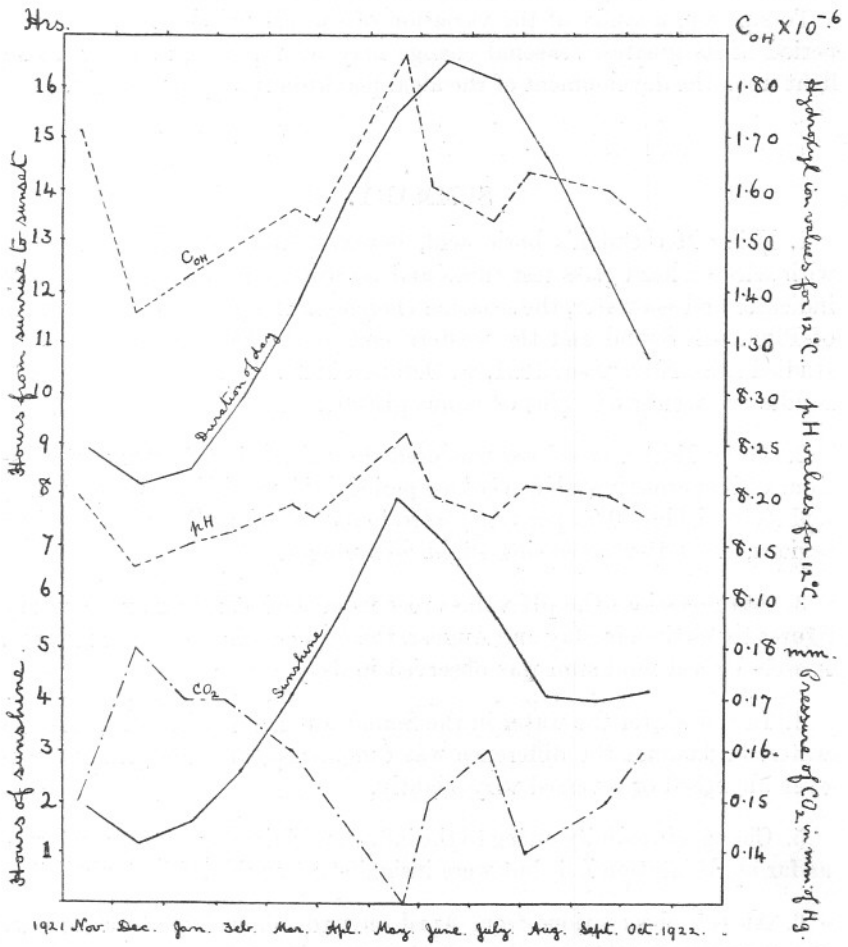


FIG. 12.

greatest in June, and greater in July than in May, yet these months witness the marked drop in alkalinity which appears to be connected with an increase in the marine fauna. In 1922, the highest percentage of sunshine, calculated on the total possible, was in May, and amounted to 51 per cent, or 7·90 hours per day. In 1921, however, the maximum was

56 per cent in April, with 7·72 hours, yet June, with 52 per cent, had 8·59 hours, the greatest amount for the year. It is accordingly clear that sunny weather coming when the days are long has the greatest effect upon the total sunshine, and therefore on the algal plankton. For example, in 1921 the months April to July inclusive averaged 7·99 hours of sunshine a day, whereas in 1922 the number was less, 6·57 hours; the difference, calculated on the latter value, amounts to 22 per cent.

To sum up, a study of the variation of the pH value throughout the period of its greatest seasonal change may be expected to throw some light upon the development of the algal plankton from year to year.

SUMMARY.

1. Using McClendon's boric acid, borax, sodium chloride standards, with selected hard glass test tubes and accurately measured amounts of indicator and sea water, the seasonal changes in the pH value of the water of Plymouth Sound and the western end of the English Channel were studied from November, 1921, to October, 1922. It is thought that the results are accurate to plus or minus pH0·01.

2. The indicator cresol red was used throughout in 0·02 per cent solution, and is perfectly stable over long periods. Thymol blue (0·04 per cent) and xylenol blue (0·02 per cent) were found useful in the more alkaline regions, the latter possessing slight advantages.

3. At all stations the pH values rose from the December and January figures to maxima in May and August, the former being the more marked. A well-defined minimum was observed in July.

4. In the winter the water in the Sound was less alkaline than the sea water, in summer the difference was diminished, and the gradient was even abolished or reversed very slightly.

5. Changes in salinity owing to the influence of river water were detected as far as the station L 4, but were insignificant at the Eddystone, L 5.

6. At E 1 observations from April onwards showed that the surface was at a higher pH value than the bottom. By July the water column had become more homogeneous, but the rise in pH near the surface during the secondary maximum in August was not finally diffused throughout the column of water till October.

7. In both 1921 and 1922 the May values for the eastern stations, E 1, E 2, E 3 were greater than the July values, whereas at N 1, N 2 and N 3

the July values are the higher. The July temperatures were in every case the greater.

8. Both temperatures and pH values show that vertical mixing of the water is at all times thorough at E 3, off Ushant, whereas at stations well out to sea, such as E 1, E 2 and N 1 the phenomenon is much less marked. This appears to be a factor of considerable biological importance.

9. The pH maximum in May, 1921, corresponds with the maximum average number of hours of sunshine daily, rather than with the length of the day, which reaches a maximum in June. The pH values for E 1, surface, corrected to 12° C., range from 8·14 in December to 8·27 in May, the change amounting to a fall of 25 per cent in the hydrogen ion concentration; for the bottom the range is pH8·13 to 8·20, a fall of 15 per cent. These changes affect amphoteric colloids in proportion to the alteration in the ratio of the hydrogen and hydroxyl ions, or in proportion to the ratio of the squares of the hydrogen ion concentrations. For the figures given the effects are in the ratios of 1·00 : 0·56 and 1·00 : 0·72 respectively.

10. The winter pH value and temperature lead to a carbon dioxide pressure of 0·17 mm., which in May is reduced to 0·13 mm. These figures correspond respectively to 2·2 and 1·7 parts of carbon dioxide per ten thousand of air, the normal atmospheric value being 3·3 parts or 0·25 mm., which would be in equilibrium with sea water at pH8·02 at 12° C. The open sea water is therefore always in a position to absorb carbon dioxide from the air.

11. In a general way the pH maxima may be correlated with the diatom maxima in early summer and in autumn, but no quantitative results have as yet been obtained on this point. The alteration in the reaction of the water may be used to make an approximate estimate of the total crop of algal plankton which has been given in Part I.

12. The variations from place to place in the pH values of the water of the English Channel are so small that they are considered to be altogether unimportant as a factor influencing the migration of fish.

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The Phosphate Content of Fresh and Salt Waters in its Relationship to the growth of the Algal Plankton.

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With Figures 1–8 in the Text.

CONTENTS.

Introduction and Phosphate Content of Fresh Water Supplies.

On account of the minute quantities in which they are present and of the fact that they are considered of secondary importance as indicating sewage contamination, phosphates are not usually estimated in analyses of natural waters. The tediousness of the determination also militated against it in the past. As a result, of the numerous analyses recorded by Clarke (1920), but few mention phosphates. C. H. Stone's analysis of the Mississippi in 1905, carried out upon a sample above Carrolton, Louisiana, shows 0·27 per cent of phosphate (PO_4) with a total salinity of 146 parts per million, or 0·39 mgrm. PO_4 per litre, corresponding to 0·29 mgrm. P_2O_5.

The presence of as little as 0·5 part P_2O_5 per million, viz. 0·5 mgrm. per litre, is considered as indicative of sewage contamination (Kenwood, 1911, quoting Hehner), though owing to the rapid removal of phosphates by plants a smaller amount need not necessarily prove the purity of the water. The American Public Health Association's Standard Methods for water analysis do not include one for phosphate (1920).

Recently McHargue and Peter (1921) have carried out a large number of phosphate determinations in small and large streams and some of the great rivers of the United States. Spring water in an Ordovician area was found to contain 0·5–0·8 parts per million of phosphate as pentoxide; springs in other areas were considerably poorer, containing only 0·1–0·2 p.p.m. Figures for the rivers Ohio, Tennessee, Green River, Cumberland, Missouri, and Mississippi averaged 0·2 p.p.m. Calculating from the mean annual volume of the Mississippi near its mouth these authors conclude that the amount of the element phosphorus carried to the sea in solution amounts each year to 62,188 tons; to this must be added the phosphorus (0·15 per cent) in 7469 million cubic feet of suspended matter. The concentration of phosphate in the sea is, as will be shown later, far less than 0·2 p.p.m., so, while diluting the general salinity of the ocean, the river raises its concentration as regards phosphates.

In view of the scanty data available as to the quantity of phosphate in natural waters and reservoirs in this country, the following miscellaneous determinations carried out by the writer may be placed on record. The analyses were made by the colorimetric method of Denigès, as described later.

In order the better to characterize the water the pH value and electrical conductivity, which gives an idea of the proportion of total solids, are also tabulated (see Table I).

It may be seen that the phosphate content of uncontaminated streams and fresh water supplies is extremely small in the districts examined, being under 0·05 parts of P_2O_5 per million. These values are considerably below those of McHargue and Peter, obtained in the U.S.A. How small these quantities are may be appreciated from the fact that Matthews (1916–18), when making up artificial sea water from the purest chemicals of Merck and Kahlbaum, found that the mixture contained 0·0286 mgrm. of P_2O_5 per litre, and the writer has found hydrogen peroxide sold as free from phosphoric acid to contain the equivalent of 0·20 mgrm. of P_2O_5 per litre.

The earlier analyses of the phosphate content of sea water are reviewed by Matthews (1916), Raben (1920), and Brandt (1920).

With samples taken just outside Plymouth Breakwater Matthews found a maximum of 0·06 mgrm. per litre at the end of December, 1915, with an irregular fall to a minimum of less than 0·01 in April and May.

He attributes the seasonal variation to the removal of phosphates from solution by the fixed algæ, the diatoms, and Phæocystis.

Raben's analyses extend from 1904–14, and include numerous determinations upon the water of the North Sea, Baltic, Barentz Sea, and North Atlantic Gulf Stream. These, as plotted by Brandt, show minimal values in May and June. After a rise to a peak in September low values are again shown early in October.

Brandt's graph, like that given by Matthews, refers to surface water, though Raben also analysed water from various depths down to 800

TABLE I.

Source of water.	Phosphate as mgrms. P_2O_5 per litre.	Electrical conductivity at 0° C. $\times 10^6$.	pH.
Plymouth tap, May	0·003	26	6·6
Maryfield (Cornwall) tap, June	0·023	270	7·2
Basingstoke tap, June	0·032	270	7·2
Peverell (Plymouth) old reservoir, June	0·278	222	—
Pool in waterlogged pasture, Anglesey	0·167	290	6·9
Stream, Bodorgan, Anglesey, February	0·019	192	6·8
Stream, basalt district, S. Scotland, March	0·007	59	6·4
Ditch, calcareous sandstone district, S. Scotland, March	0·016	186	6·9
Stream, S. Scotland, March	0·021	72	6·8
Stream, Yorkshire, March	0·036	227	7·1
Stagnant ditch, meadow, near Plymouth	0·019	213	7·7
Ditch in lane, near Plymouth	0·047	294	7·6
Yard well, Antony, Cornwall	1·25	227	6·4
Sea water, winter	0·049	28,200	8·1
Aquarium tanks, Plymouth	4·81	30,300	7·6

metres in the North Atlantic. There is usually a considerable increase from the surface downwards. None of the values, however, indicate exhaustion of the water as regards phosphate, the minimum recorded figure being 51 mgrm. of P_2O_5 per cubic metre (viz. 0·051 mgrm. per litre) and the maximum 221 mgrm., both values being from North Sea Station N7. These figures are about four times as great as those given by Matthews, whose results it may be added agree well with those obtained by the Government chemist, London, using the same method as Matthews upon samples sent from Plymouth in 1922, and with analyses carried out by the writer, according to an entirely different method.

In view of the importance of phosphates for plant growth it seemed of interest to make a further study of these seasonal changes, both in the sea and in fresh water, and to study the diminution of phosphate in laboratory cultures.

The Uptake of Phosphate in a Diatom Culture.

A culture of *Nitzschia closterium* W. Sm., pure save as regards the presence of bacteria, was kindly supplied by Dr. E. J. Allen. This was growing in sea water enriched with Miquel's solution, as described by Allen and Nelson (1910). It was exposed in a north window for periods as given in Table 2, the temperature being about 12°–15° C. The results are shown in Fig. I, and it may be seen that a great increase in diatoms results in the almost complete utilization of the phosphate, which appears to be the factor limiting further multiplication.

TABLE II.

Changes in phosphate in culture flask of *Nitzschia closterium*.

Date.	Days.	Nitzschia, thousands per c.c.	P_2O_5 as milligrams per litre.		
17/3	0	0	—	—	—
27/3	10	510	2·38	—	—
13/4	26	2140	0·55	—	—
26/4	40	3065	0·006	—	—

From the count of 13/4 and the previous one 1630×10^6 diatoms use up 1·83 mgrm. P_2O_5, namely, 1×10^9 require 1·12 mgrm. From the final count 925×10^6 diatoms have appeared at the expense of 0·544 mgrm., which is equivalent to 0·59 mgrm. per 1×10^9 diatoms. This being considerably less, about half, the former value indicates either a reduction in size of the diatoms, which may result from their mode of division, or else a regeneration of phosphate from the protoplasm of dead diatoms ; the hæmacytometer count includes all diatoms, but the number given may not all be alive.

An attempt was made to settle this point by estimating the phosphate content of a known number of diatoms. Accordingly 105 c.c. of Nitzschia culture was filtered through close-grained paper, and evaporated to dryness with hydrochloric acid, in order to decompose organic compounds containing phosphoric acid. The residue was then taken up with water, and since the culture contained $2{\cdot}9 \times 10^6$ diatoms per c.c., as read from the graph for the date of the analysis, it was ascertained that 0·307 mgrm. of P_2O_5 was yielded by 1×10^9 diatoms. Another portion

of the culture was taken later on, and submitted to the more drastic treatment of evaporation to dryness with nitric acid. The residue was then evaporated to dryness after having been taken up with water, and, finally, after the addition of sulphuric acid. The culture at this stage contained $3{\cdot}06 \times 10^6$ diatoms per c.c. and 0·303 mgrm. P_2O_5 per 1×10^9 diatoms was obtained, which agrees closely with the first analysis. Since the amount is, however, only about one-fourth of that taken up by the production of this number of diatoms it appears that the treatment

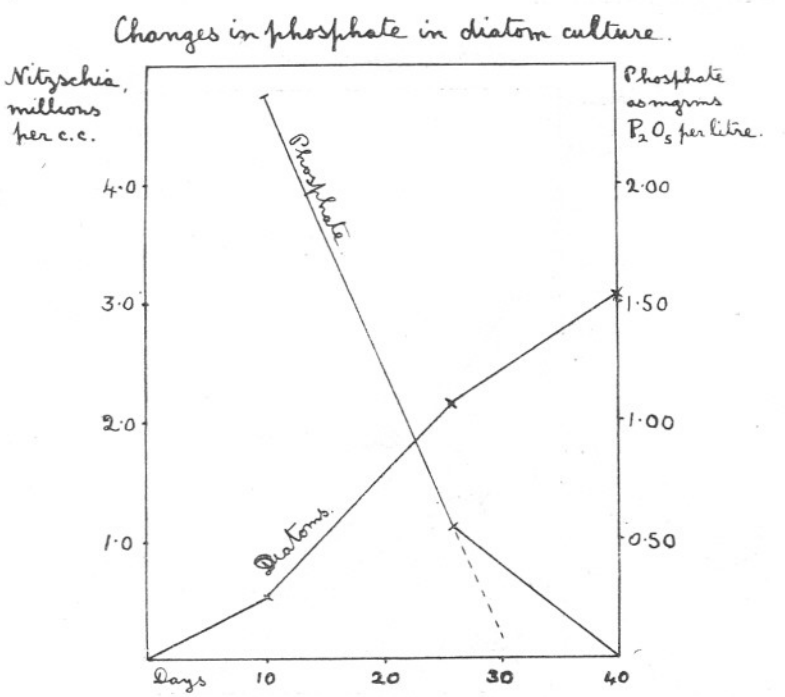

FIG. 1.

has not sufficed to convert all the organically combined phosphorus into the acid, but has split off a more easily hydrolysed fraction of it. The estimation of the total phosphorus has been deferred till a later date.

As 1×10^9 of the diatom require 1·12 mgrm. P_2O_5, one gram of this should suffice for 9×10^{11} Nitzschias. It now becomes of interest to study the seasonal change in phosphate which occurs in sea water, and to estimate the Nitzschia crop that could be produced were the whole amount available for this organism, neglecting any processes that may enrich the sea with phosphate during its period of diminution.

THE DECREASE IN PHOSPHATE OCCURRING IN STORED SEA WATER WHEN INSOLATED.

Open sea water stored in the dark in bottles used for chloride samples, or in Winchester quart bottles, appears to undergo but little change for a couple of weeks in spring. There is, however, always the possibility that owing to the growth of moulds water kept for considerable periods may give low results, or even possibly high results, if bacterial decomposition has been active, though on the latter point there is as yet no direct evidence.

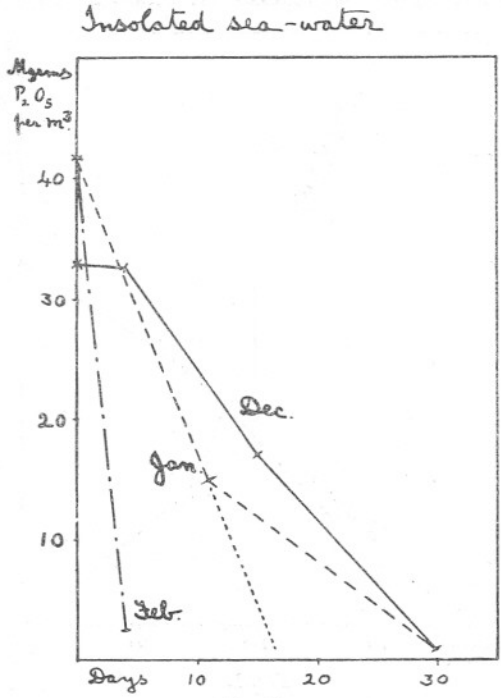

FIG. 2.

In order to test the hypothesis that the vernal decrease observed to occur in the sea was due to the uptake of phosphate by algæ, five Winchester quart bottles of water were exposed in a south window. Of these A and B were taken from Station E1 on December 18th and January 16th respectively, C and D at Station L5, the Eddystone, in quite similar sea water on February 12th and March 8th, whilst E was from L1 in Plymouth Sound. On insolation A and B decreased slowly at first, but only 0·001 mgrm. P_2O_5 per litre was left after thirty days. The others, however, contained only 0·003 mgrm. per litre after four days. The results are shown in Table III and Fig. 2.

TABLE III.

Changes in phosphate content of stored sea water when insolated. Phosphate in milligrams of P_2O_5 per cubic metre. Insolated from 24/3/23.

Sample	A	B	C	D	E
Source of water: Days.	E1, 18/12/22.	E1, 16/1/23.	L5, 12/2/23.	L5, 8/3/23.	L1, 7/3/23.
0	33	42	42	37	43
4	32·5	—	2·5	3	3·5
11	—	15	—	—	—
15	17	—	—	5	—
30	1	1	—	—	—

On account of their similarity to the line given by C, those for D and E have been omitted from the figure. It is evident that the diminution in phosphate becomes increasingly rapid as the spring samples are approached; the explanation appears to be that these contain a larger number of plankton algæ per unit volume, and their multiplication under the favourable light conditions speedily results in the consumption of the small amount of phosphate occurring in sea water. As many as 464 plankton organisms per cubic centimetre have been found by Allen (1919) in sea water in summer. In winter, however, the much smaller numbers present can apparently be doubled or quadrupled with but little effect upon the amount of phosphate as ascertained by analysis.

The figures obtained make it clear that, just as in the Nitzschia culture, which was artificially enriched with nitrates, in sea water also algal growth results in the uptake of phosphate till none remains, for a quantity such as 0·001 mgrm. per litre (viz. 1 in 10^9) is about the limit which can be detected by the extremely delicate method used. Recent work by Pentanelli (1923), of which an abstract only has been seen, claims to show that the development of marine algæ in unchanged sea water is stopped by deficiency in carbon dioxide, nitrogen, and phosphorus, and by an alteration of the water which is independent of the consumption of food.

In this connection it may be remarked that Allen and Nelson (1910) found that the tank water was more favourable, when sterilized, for the cultivation of diatoms than was open sea water. This is, no doubt, due in part at least to its higher phosphate content. It may also be added that the Laboratory supply of open sea water filtered through a Berkefeld candle, as explained by Allen and Nelson, was found, after standing in a covered beaker for a fortnight, to contain less than 0·01 mgrm. P_2O_5 per litre, whereas water freshly drawn contained 0·12 mgrm. Sea water at the time had about 0·049 mgrm. When filtered through a Doulton filter candle, which had been well washed with tap water containing

under 0·02 mgrm. P_2O_5 per litre, sea water was deprived of phosphate. After rejecting the first portion likely to be diluted by fresh water, the next 80 c.c. was found to have 0·020 mgrm. per litre. A further 300 c.c. gave 0·026 mgrm. None of the sea water analyses recorded by the writer were made upon filtered water unless expressly stated to the contrary.

As mentioned in the analytical section of this paper, Matthews used ferric chloride solution to precipitate the phosphate of sea water for estimation. It was found by the writer that on adding a few drops of Laboratory reagent ferric chloride all phosphate was removed with the ferric hydroxide precipitate and the filtered solution contained not more than 0·001 mgrm. P_2O_5 per litre.

With water from the Aquarium tanks containing 4·75 mgrm. P_2O_5 per litre the addition of ten drops of ferric chloride to a beaker containing about a litre reduced the phosphate to 0·62 mgrm. and the pH value from 7·6 to 6·7. A further ten drops brought the reaction to pH6·6 and the phosphate down to 0·01. On bringing the total number of drops up to thirty, a great increase in acidity, pH3·4, was found, together with an increase in the phosphate in solution. One drop of 0·880 ammonia, however, made the solution alkaline, about pH10, and reduced the phosphate to 0·005 mgrm. per litre. This action of iron in precipitating phosphate is of much biological importance, and should be considered when culture media are being prepared.

Seasonal Changes in Phosphate in Sea Water, 1922 results.

Table IV shows seasonal variations of phosphate, expressed in milligrams of P_2O_5 per litre ; the analyses were carried out on surface samples stored for some weeks at the Government Chemists' Laboratory, London, by Pouget and Chouchak's colorimetric method, as used by Matthews.

TABLE IV.

Date.	L2 and L3.	E1.	E2.	E3.	N2.
12/2/22	0·051	—	0·070	—	0·016
15/3	—	0·046	—	—	—
30/3	0·034	0·039	—	—	0·041
25/5	—	—	—	0·022	0·031
6/6	0·012	0·015	—	—	—
12/7	—	0·019	—	0·020	0·019

Aquarium of the Marine Biological Association, east reservoir, about 5·0 mgrm. per litre.

As already mentioned, these results agree well with those obtained by Matthews in 1916, his site, the Knap Buoy, being in between stations L2 and L3. They further show that these changes occur simultaneously in the sea water over a wide area. It should be explained that the L series of stations extend from below the Laboratory, in Plymouth Sound to L6, which is half-way between the Eddystone (L5) and E1. The remainder are the International Hydrographic Stations, E1, E2, and E3, lying on the course from the Eddystone to Ushant, N1, N2, N4, and N5, on the course from Ushant to Cork Harbour. N3 is between the Scilly Islands and Cornwall, E6 being 20 miles to the north in the Bristol Channel. Their positions are shown in the map given by the writer (1922).

The relatively high value 5·0 mgrm. per litre given by the water of the Aquarium is noteworthy, as it indicates the mode, or one mode, whereby the phosphate taken up by the algal plankton is returned again to the sea—namely, through the excretion of phosphate by fish and marine invertebrates. The tanks are well stocked with both, but there is little algal life, so the normal balance of the sea is disturbed.

It may be added that similar values for the tank water have been obtained by the writer, viz. 4·75 mgrm. per litre for both east and west reservoirs on April 10th, 1923, and 4·81 mgrm. on June 29th. The reservoirs had been drained and refilled between these analyses and that of the Government chemist.

Seasonal Changes in Phosphate at L Stations, 1923.

The work was continued in 1923, all the determinations being made by the writer according to the method of Denigès, upon samples taken the same or the preceding day. The samples were kept in the dark during the interval.

Table V gives the results for the L series from March to August. Certain values for water taken at the east slip, directly below the Laboratory, are also included. Owing to sewage contamination these do not exhibit regular seasonal changes. The effect of sewage upon the L1 values is surprisingly small, judging by the uniformity of the figures with those of other stations. Low values were obtained from the end of April onwards, and Fig. 3 represents the seasonal change at L4, half-way between Rame Head and the Eddystone, about five miles outside the Breakwater.

Within the limits of experimental error the surface values are equal to or less than the bottom, due to the fact that photosynthesis and consequently algal growth and reproduction is more active near the surface. Occasionally, however, one meets with an abnormal surface

value, such as that for L4 on May 31st and L6 on August 15th. One can only attribute these results to a local contamination of the water from a ship, as the bucket had been rinsed repeatedly, as were also the bottles.

TABLE V.

Seasonal variations of phosphate, expressed in milligrams of P_2O_5 per litre, surface samples mainly.

Date.	East slip.	L1.	L2.	L3.	L4.	L5.	L6.
7/3/23	0·0485	0·0485	0·049	0·049	—	—	—
12/3/23	—	0·049	0·045	—	0·041	0·033	—
21/3/23	—	0·042	0·040	0·041	—	0·038	—
22/3/23	0·0395	—	—	—	—	—	—
27/3/23	—	—	—	0·020*	—	—	—
28/3/23	—	0·032	0·033	0·039	0·037	—	—
9/4/23	—	0·033	0·033	—	—	—	—
9/4/23	—	0·036B	0·033B	—	—	—	—
11/4/23	—	—	—	—	—	0·031	—
11/4/23	—	—	—	—	—	0·041B	—
16/4/23	—	0·021	0·020	0·013	0·016	0·023	—
16/4/23	—	0·024B	0·024B	0·018B	0·028B	0·021B	—
18/4/23	—	—	—	0·024	—	—	—
18/4/23	—	—	—	0·024B	—	—	—
20/4/23	—	0·024	—	—	0·014	0·024	—
20/4/23	—	0·028B	—	—	0·027B	0·023B	—
24/4/23	—	0·016	0·010	0·015	0·021	0·023	—
3/5/23	0·042	—	—	—	—	—	—
7/5/23	—	0·027	0·025	—	0·023	—	—
7/5/23	—	—	—	—	0·023B	—	—
22/5/23	—	0·0235	0·0155	0·023	0·0105	0·012	0·004
31/5/23	—	—	—	0·0065	0·050†	—	—
31/5/23	—	—	—	0·0065B	0·046†	—	—
31/5/23	—	—	—	—	0·008B	—	—
19/6/23	—	0·0045	—	0·0055	—	0·004	—
19/6/23	—	0·009B	—	0·0115B	—	0·012B	—
23/6/23	0·008	—	—	—	0·009	—	—
2/7/23	—	—	—	—	0·013	—	—
2/7/23	—	—	—	—	0·013B	—	—
10 & 12/7/23	—	—	—	0·013	0·014	0·0135	0·007
10 & 12/7/23	—	0·017B	0·019B	0·017B	0·016B	0·014B	—
15/8/23	—	0·017	0·019	0·017	0·010	0·020	0·032
15/8/23	—	—	—	0·017B	0·021B	0·019B	0·020B

The general trend of the seasonal changes in the L series is illustrated in Fig. 3, in which are plotted the results for L4. The abnormal result for May 30th has been omitted, and the bottom value taken for surface also since L3 had identical values for both on that date ; these differed

* Mean of two samples. B indicates bottom sample.

† Abnormal result verified by analysis on two bottles.

only by 0·0015 from the L4 bottom value. The curve is similar to that obtained by Matthews, save that the seasonal changes are about a month later all through. Comparison with the bottom values shows how a low surface value in April may so quickly be followed by one over twice as great; clearly the deeper water acts as a reservoir of phosphate, as is more fully shown in subsequent figures. The higher bottom value found in August indicates that the regeneration of phosphate takes place in the deeper water, or rather that its effect is more evident there since it is being rapidly removed at the surface in summer.

It seemed possible that these changes could be detected in rock pools, exposed for several hours each tide.

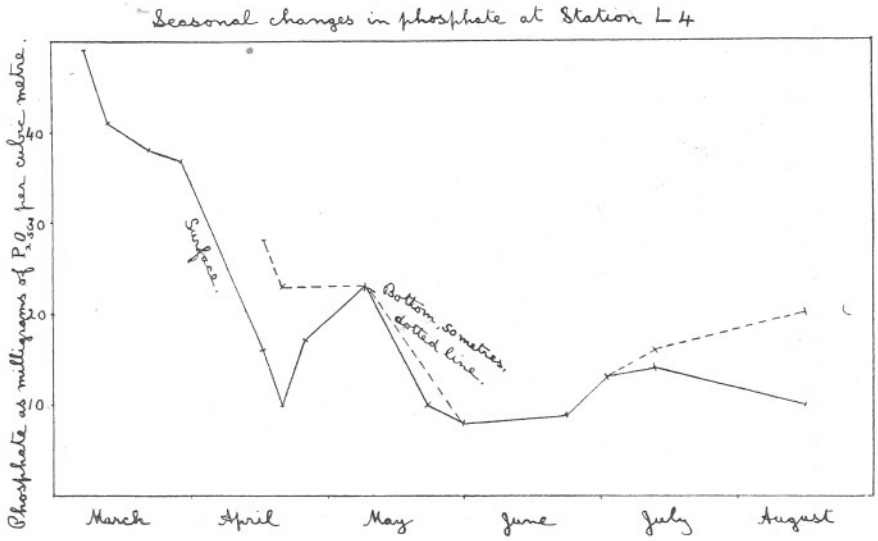

FIG. 3.

It was at first thought permissible to compare the pool water with that taken about a hundred yards to the east at the slip, but results given in Table VI (page 133) show that sewage contamination renders this unreliable. As far as the analyses go they indicate an increase in phosphate in the pools during their separation from the sea on two days, but an appreciable decrease one very sunny day. The pools have an abundance of animal life as well as algæ, so excretion may account for the small increases noted.

SEASONAL CHANGES IN PHOSPHATE AT THE INTERNATIONAL HYDROGRAPHIC STATIONS E1–E3 AND N1–N3.

Table VII (page 133) contains the results of the analyses of sea water taken at E1 from March to August at various depths. From the end of

May onwards the surface water may be seen to be almost totally devoid of phosphates. Fig. 4 makes this clear, and an increase in the phosphate content of the bottom water in August is also noticeable. Fig. 5 illustrates the variations in phosphate with depth; the seasonal change is here shown by the shifting of the curve to left for diminution or to right or increase. Bad weather precluded the taking of a February series, but the sea water was apparently richer in phosphate then than in March, judging from Matthews' results.

The differences which exist, in the calmer summer weather, between

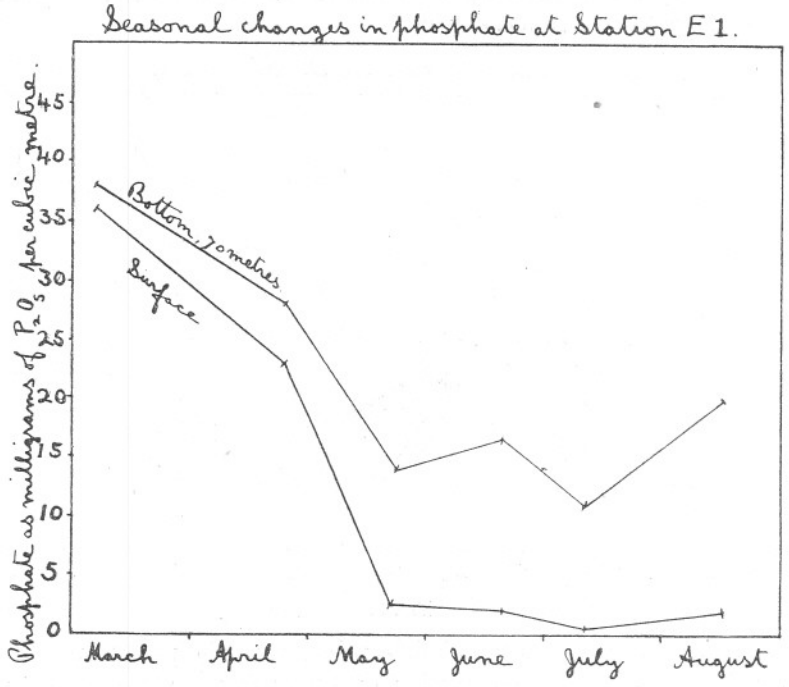

FIG. 4.

surface and deeper water samples show that mixing of the water is not rapid at E1 at this season. On account of the diminution in the intensity of the light the phosphate in the deeper water is not used up till it is brought nearer the surface, or at least it is used up at a greatly reduced rate.

In Table VIII (page 134) the corresponding data are given for Stations E2 and E3. The depth series results are plotted in Fig. 6 (page 132). Samples taken on the cruises to Ushant, etc., have perforce to await analysis for two to three days, but no appreciable error appears to be introduced by this as the samples are stored in the dark.

The almost total depletion of the phosphate down to 10 metres is noticeable at E2, and here, as at E1, the minimum value is found in July. At E3, however, the May value is the lowest for the bottom, and the mixing of the water diminishes the surface to bottom gradient.

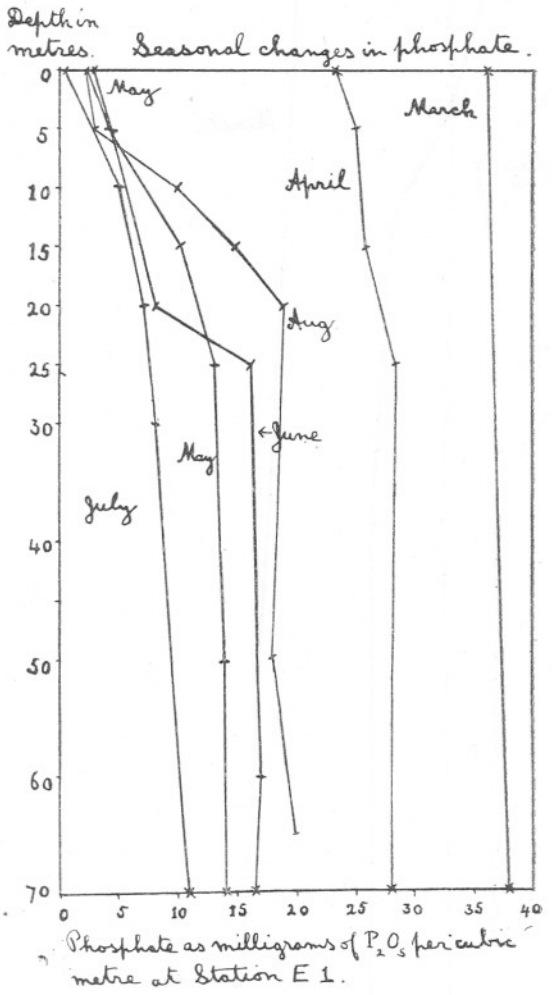

FIG. 5.

This has also been observed as regards temperature and pH gradients at this station, as pointed out by the writer in an accompanying paper in this Journal.

For Stations N1, N2, and N3 no April records are available owing to the renewal of stormy weather during the cruise, and a thick fog

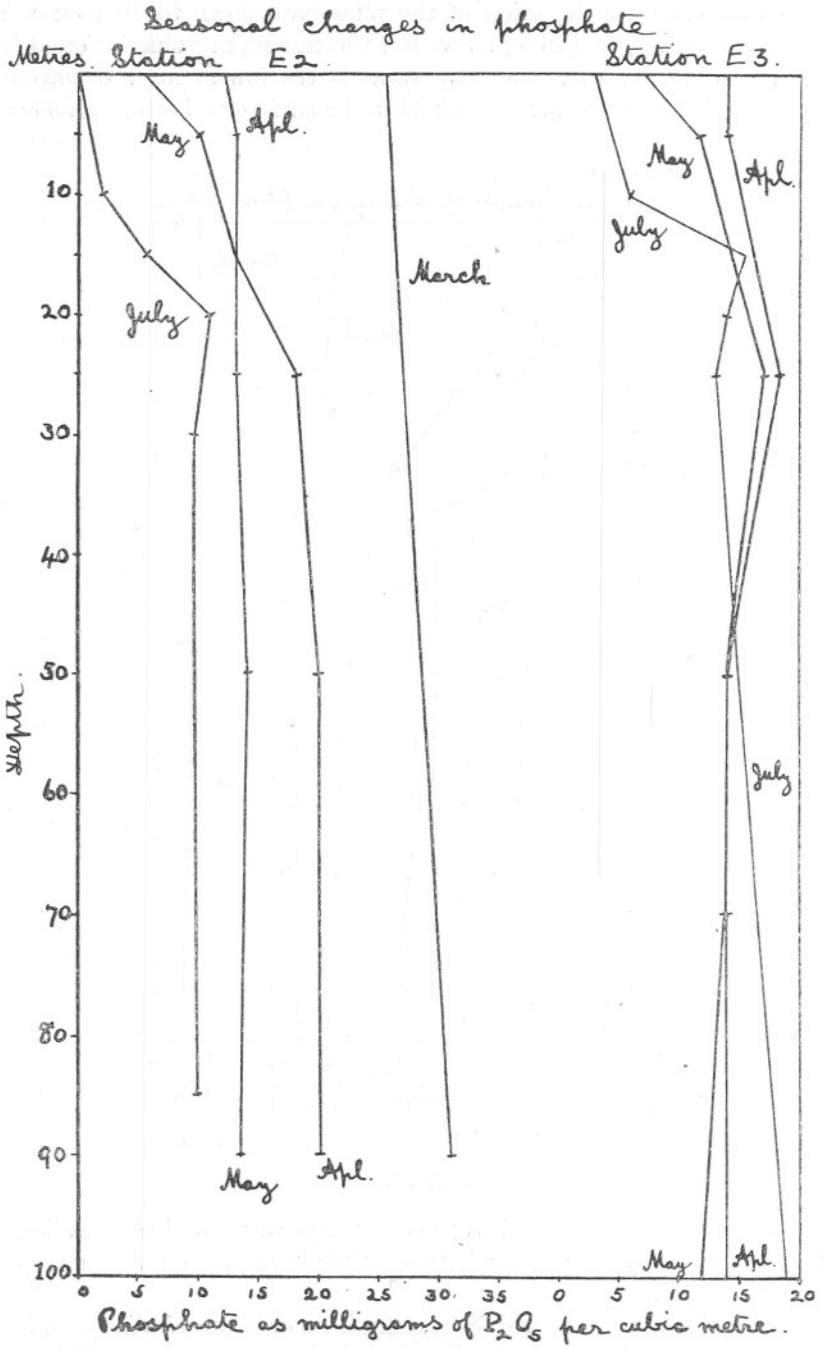
Seasonal changes in phosphate
Metres.
Station E 2.
Station E 3.
May
Apl.
July
March
May
Apl.
July
May
Apl.
July
May
Apl.
Depth.
10
20
30
40
50
60
70
80
90
100
0 5 10 15 20 25 30 35 0 5 10 15 20
Phosphate as milligrams of P_2O_5 per cubic metre.

FIG. 6.

prevented the obtaining of samples at N3 in July. The analyses for May and July are given in Table IX (page 134) and plotted in Fig. 7 (page 135). At both N1 and N2 the July values are greater than those for May in the samples from the deeper water. The gradient is also very remarkable, especially the difference between the 15- and 20-metre samples at N1. The settled calm weather appears to account for this. There is a suggestion of regeneration of phosphate at both N1 and N2, or the higher values may be due to a transgression of deeper water moving eastwards over the edge of the west European submarine shelf.

TABLE VI.

Source of water.	Date.	Hour.	Phosphate as mgrms. P_2O_5 per litre.	Notes
East slip . .	3.4.23	11.40 a.m.	0·031	
Rock pool west of slip . .	,,	11.50 a.m.	0·037	
Do. . . .	,,	2.50 p.m.	0·040	
East slip . .	4.4	11 a.m.	0·033	
Do. . . .	,,	5 p.m.	0·0325	
Rock pool . .	,,	12.50 p.m.	0·036	
Sound, by pool .	,,	,,	0·036	
Another pool, close to first one	,,	4 p.m.	0·040	First pool submerged.
East slip . .	5.4	10.15 a.m.	0·039	
Rock pool . .	,,	12.30 p.m.	0·039	Pool covered at 10.30 a.m.
Sea by pool . .	,,	,,	0·039	
Pool . . .	,,	4.15 p.m.	0·030	Very sunny day.
East slip . .	,,	4.15 p.m.	0·055	Sewage effect.

TABLE VII.

Seasonal variations of phosphate, expressed in milligrams of P_2O_5 per litre, Station E1.

Depth in metres.	March 7th	April 24th.	May 22nd.	June 19th.	July 10th.	August 15th.
0	0·036	0·023	0·0025	0·002	0·0005	0·002
5	—	0·025	0·004	0·004	—	0·003
10	—	—	—	—	0·005	0·010
15	—	0·026	0·010	—	—	0·015
20	—	—	—	0·008	0·007	0·019
25	—	0·0285	0·013	0·016	—	—
30	—	—	—	—	0·008	—
50	—	—	0·014	—	—	0·018
60	—	—	—	0·017	—	—
70	0·038	0·028	0·014	0·0165	0·011	0·020

TABLE VIII.

Seasonal variations of phosphate, expressed in milligrams of P_2O_5 per litre, Stations E2 and E3.

Depth in metres.	March 14th.	April 24th.	May 22nd.	July 10th.	April 25th.	May 22nd.	July 10th.
0	—	0·012	0·0055	0·000	0·014	0·007	0·003
5	0·0255	0·013	0·010	—	0·014	0·0115	—
10	—	—	—	0·002	—	—	0·006
15	—	0·013	0·013	0·0055	—	—	0·0155
20	—	—	—	0·011	—	—	0·014
25	—	0·018	0·013	—	0·0185	0·017	0·013
30	—	—	—	0·0095	—	—	—
40	—	—	—	—	—	—	—
50	—	0·020	0·014	—	0·014	0·014	—
60	—	—	—	—	—	—	—
70	—	—	—	—	—	0·014	—
80	—	—	—	0·010	—	—	—
90	0·031	0·020	0·0135	—	—	—	—
100	—	—	—	—	0·014	0·012	0·019

TABLE IX.

Seasonal variations of phosphate, expressed in milligrams of P_2O_5 per litre, Stations

	N1		N2.		N3.
Depth in metres.	May 22nd.	July 11th.	May 22nd.	July 11th.	May 22nd.
0	0·015	0·0045	0·017	0·014	0·016
5	0·016	—	0·015	—	—
10	—	—	—	—	—
15	0·013	0·005	—	0·014	—
20	—	0·022	—	0·015	—
25	0·016	0·021	0·015	0·0235	0·016
30	—	—	—	—	—
40	—	—	—	—	—
50	0·017	—	0·016	—	—
60	—	—	—	0·0235	0·0205
70	0·017	—	—	—	—
80	—	—	—	—	—
90	—	0·023	0·022	—	—
105	0·019	—	—	—	—

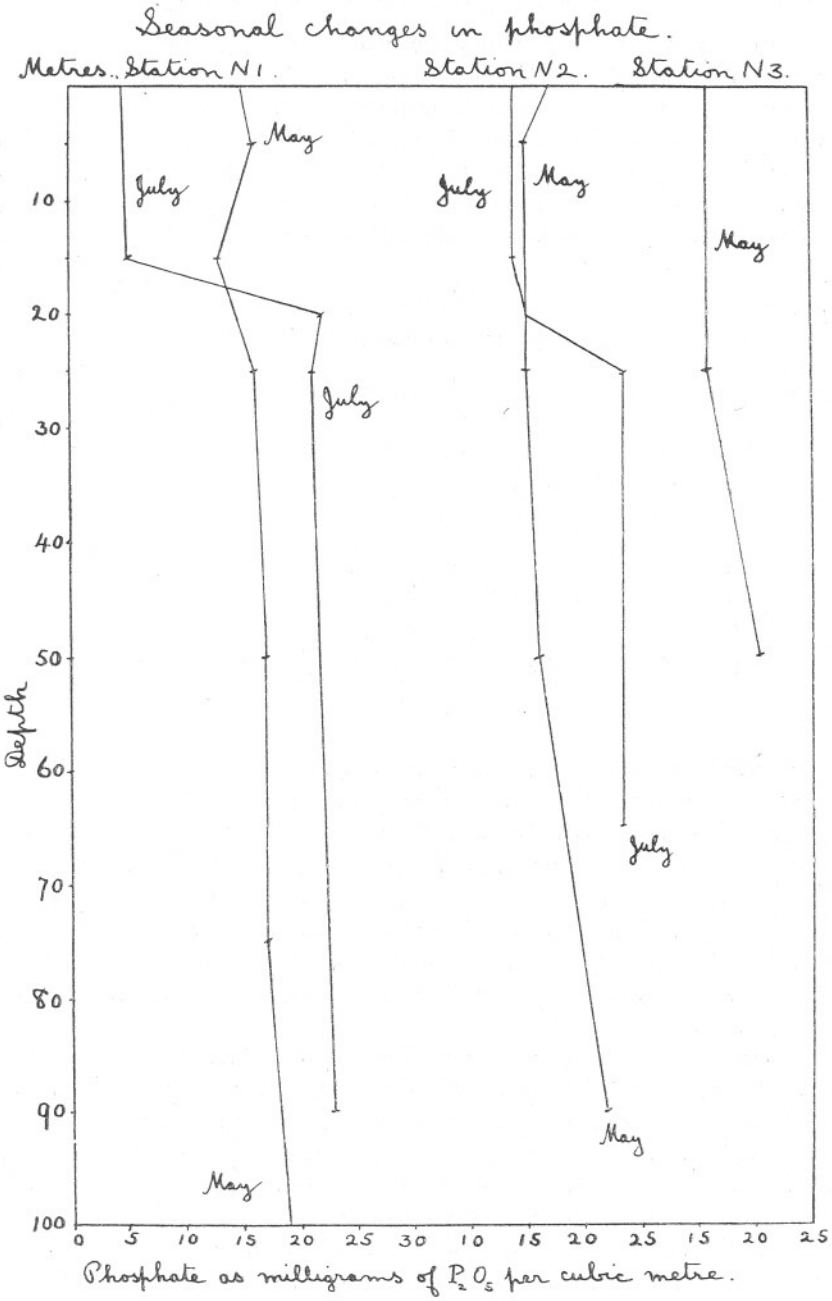
Seasonal changes in phosphate.
Metres.
Station N1.
Station N2.
Station N3.
May
July
July
May
May
July
July
May
May
July
May
Depth
10
20
30
40
50
60
70
80
90
100
0 5 10 15 20 25 30 10 15 20 25 15 20 25
Phosphate as milligrams of P_2O_5 per cubic metre.

FIG 7.

Phosphate Content of the North Sea.

Since many of the determinations made by Raben were carried out upon water from the North Sea, it seemed to be of interest to examine samples from that region also in order to see whether values in better agreement with his results would be obtained. This was rendered possible through the courtesy of Dr. E. S. Russell, Director of the Fisheries Laboratory, Lowestoft, and of Mr. J. R. Lumby, who kindly collected the water samples. The analytical results are shown in Tables X and XI.

TABLE X.

Phosphate in North Sea, surface samples, April to July.

Date.	Position.	Lat. N.	Long.	Phosphate as mgrms. P_2O_5 per cubic metre.
13/4	Cross Sand Lightship .	—	—	35
,,	Inner end of Stanford Channel, Lowestoft .	—	—	40
,,	10′ E.×N. from Tyne .	55° 4′	1° 8′ W.	36
,,	60′ E.×N. from Hartlepool	55° 8′	0° 22′ E.	36
3/5	Do.	55° 23′	1° 22′ W.	15
11/7	Off Newbiggin Point .	55° 15′	1° 20′ W.	8
25/7	18′ N.E.×E. Tyne .. .	—	—	11

It may be seen from Table X that the values found are quite similar to those for the English Channel for the same months.

Table XI also gives figures quite in accord with those found off Plymouth, but far lower than Raben's values for North Sea water. It should be noted that the figures in Table XI are not as uniform as might be expected, as in several instances the surface values are slightly higher than the bottom. This may be connected with the circumstance that there was a delay of one month between the collection and analysis of these samples.

Of especial interest are the results for Stations 24 and 25 in the deeper water off the coast of Norway. The 280-metre sample is two and a half times as rich in phosphate as is the surface water; again, there is over twice as great a concentration of phosphate at the bottom at Station 25 as at Station 23, with a depth of 70 metres. Near a coast there is usually more vertical mixing of the water than there is at stations well out, such as E2 and N1, accordingly one may expect an abundant plankton where deep water approaches the land or a submerged bank which causes upwelling. The phosphate values found support the views put forward by Natterer in this connection.

TABLE XI.

Phosphate in North Sea, England to Norway, May 3rd to 6th, 1923.

Station.	Lat. N.	Long.	Depth in metres.	Phosphate as mgrms. P_2O_5 per cubic metre.	Notes.
1	54° 32′	0° 2′ W.	0	21	Near Tyne.
1	,,	,,	60	19	
2	54° 39′	0° 11′ E.	0	19	
2	,,	,,	65	15	
8	54° 54′	0° 34′	0	17	
8	,,	,,	70	23	
10	55° 23′	1° 22′	0	15	
10	,,	,,	55	17	
13	56° 8′	2° 35′	0	14	
13	,,	,,	70	16	
14	56° 26′	3° 0′	0	17	
14	,,	,,	65	17	
15	56° 38′	3° 24′	0	25	
15	,,	,,	60	19	
16	56° 31′	3° 37′	0	11	South of usual course.
16	,,	,,	60	16	
18	56° 45′	3° 36′	0	20	
18	,,	,,	50	17	
22	57° 0′	4° 5′	0	18	Course more northerly, heading to Udsire.
22	,,	,,	60	18	
23	57° 30′	4° 15′	0	14	
23	,,	,,	70	17	
24	57° 59′	4° 25′	0	14	
24	,,	,,	100	24	
25	58° 28′	4° 34′	0	14	
25	,,	,,	280	36	

Seasonal Changes in the Phosphate Content of Fresh Water.

The changes occurring in the sea are naturally not without a parallel in fresh water, the study of which shows how minute is the amount of

phosphate left unabsorbed by the plankton during the summer. The fresh waters available for study were as follows :—

Staddon reservoir.—This is a cement-walled tank 22×8 metres and about 2 metres in depth. It receives surface drainage water in wet weather, and at all times it receives through an inlet pipe the overflow from a small spring, which may very well be contaminated as it issues out. This is situated at about 200 feet elevation on the east of Plymouth Sound, upon the Staddon Grits, a formation of the Lower Devonian. There are no trees surrounding it.

Maryfield quarry pond.—This has precipitous slaty sides and seems to depend upon rainfall for its water, though it may be replenished by a small spring below water level, and in very wet weather some surface water may find its way in. It is situated upon Middle Devonian Slates in the Antony district of Cornwall, about five miles east of Staddon and at an elevation of about 150 feet. It is surrounded by trees, which shade it to some extent. The dimensions are roughly 80×80 metres, with a depth of 2 to 3 metres in the middle.

Plymouth tap is supplied from Burrator Reservoir on Dartmoor.

TABLE XII.

Seasonal changes in phosphate, expressed in milligrams of P_2O_5 per cubic metre.

Date.	Staddon Reservoir.	Inlet.	Date.	Maryfield, quarry pond.	Date.	Plymouth, town tap.
19/8/22	32*	—	21/10/22	59*	—	—
2/10	91*	—	21/1/23	57*	27/1/23	19*
4/11	75*	—	18/2	42*	—	—
23/2/23	128*	119	30/3	14	31/3	3
3/4	3·5	—	15.4	5	—	—
16/4	2	82	24/4	0	—	—
1/5	6	112	6/5	0·5	1/5	3
30/5	0	81	2/6	3	5/6	0·5
15/6	11	78	24/6	3	—	—
23/6	19	60	—	—	—	—
29/6	15	86	30/6	3	5/7	5·5
26/7	9	116	26/7	3	30/7	1·5
24/8†	0	100	24/8	0	24/8	0

* Stored till analysed early in April.

† A slight turbidity in all three samples rendered the tint impossible to match with exactness. They were taken after rain.

The phosphate analyses are shown in Table XII, and are plotted in Fig. 8. It might be thought that the phosphate values were largely influenced by dilution with rain water, but electrical conductivity measurements show that this is not the case. That for the Staddon inlet is quite usual for a calcareous water, the reservoir values are some-

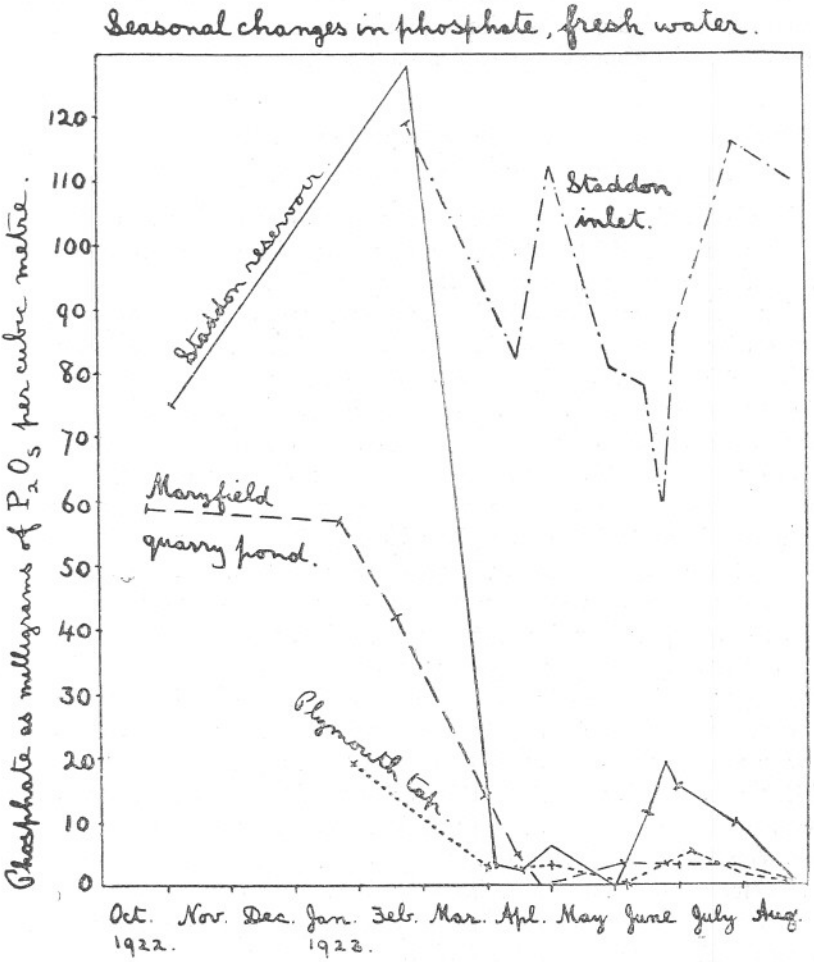

FIG. 8.

what lower. Maryfield quarry pond has, as a rule, a lower conductivity than has Staddon reservoir, and both are alkaline, around pH8 according to the season. Burrator water is at pH6·4–6·8, and its conductivity is only about one-tenth that of Staddon inlet. Though these waters are so different, two being quite " hard " and one very " soft," yet their changes in phosphate are closely similar, as may be seen in Fig. 8. It must be

pointed out, however, that the winter values given may be somewhat too high, since it is possible that phosphate was regenerated from plankton —more plentiful near the surface—during the period of storage. In general the Staddon reservoir has a much more abundant plankton during summer than has the Maryfield pond. In it the vernal outburst is followed by a period when but little algal life is found. The former becomes rich owing to its minute plankton and floating masses of Spirogyra, etc., absorbing the phosphate supplied by the inlet pipe.

Approximate estimation of the Algal Plankton Crop and of Fish Production based on Phosphate Content.

In the section dealing with the Nitzschia culture it was shown that the production of 1×10^9 diatoms of the species grown consumed 1·12 mgrm. of phosphate reckoned as the pentoxide.

By measuring the areas between the ordinate and the March and July curves for phosphate at Station E1, as given in Fig. 5, it was ascertained that 2070 mgrm. of P_2O_5 was consumed in the water column from 70 metres to the surface, having one square metre as its base. In other words, an average content of 37 mgrm. per cubic metre on March 7th had by July 10th fallen to 7·4 mgrm. In round numbers there was a consumption of 30 mgrm. per cubic metre or 2·1 grm. in the whole column. If the winter value be taken at 49 mgrm., the value found at L3, the consumption may be taken as 40 mgrm. in the same period.

Taking, however, the lower figure which was directly determined and the phosphate factor for diatom production, namely, 1·12 mgrm. per 1×10^9 diatoms, it may be seen that each litre of water could produce $26{,}800 \times 10^3$ diatoms of this species, provided nothing else grew in the water. Up to 30,000 diatoms per c.c. were found by the writer in a fresh water pond. These may be compared with the figures 462×10^3 and 464×10^3 given by Allen (1919) as the minimum values for plankton organisms per litre found early in August and September in sea water between Stations L2 and L3. The value found in the sea is only 1·7 per cent of that calculated from the phosphate consumption, because the algal plankton is eaten up by the smaller animal organisms, and serves indirectly as the food of all animal life in the sea.

Converting the above estimate per litre into per cubic metre it is seen that $26{\cdot}8 \times 10^9$ diatoms could be produced, or in the 70-metre column the enormous number 188×10^9. To be able to convert the numbers into weight it is necessary to either weigh diatoms directly or to know their phosphate content. An approximation to this may be obtained as follows: According to figures quoted by Czapek (1921) and Strasburger (1921) leaves may be taken as containing phosphate as pentoxide equiva-

lent to 15 per cent of their ash. Leaves were chosen as being assimilating organs, and so nearer to algæ than other parts such as wood or roots. Taking the ash as 10 per cent of the dry weight and the latter as 10 per cent of the moist weight, the phosphate content of the fresh plant is 0·15 per cent. Making the approximation 0·2 per cent P_2O_5 as the phosphtae content of diatoms, and using the value 2·1 grm. P_2O_5 as the amount consumed in the whole column, it follows that 1·05 kilograms of diatoms could be produced; as a matter of fact if diatoms are not produced other unicellular algæ are, and their phosphate content must be very similar.

After this estimate was made, data relating to the phosphate content of algæ were found in the Fertilizer Resources of the U.S.A., pp. 225–9. Analyses by Barlow for three species of Fucus give 0·43 per cent phosphate on the dry weight. Determinations quoted from Tom show that Fucus has 24·2 per cent dry weight, which leads to the value 0·11 per cent phosphate on the wet weight. Tom's figure, 17·7 per cent for the dry weight of Laminaria, may be rounded off as 20 per cent, since there is a considerable variation; combining this with the value given by Russell, 0·66 per cent as a maximum for phosphate calculated on the dry weight the value for the wet weight works out at 0·13 per cent. Analyses made at the Connecticut State Experimental Station give as a mean for five algæ 0·14 per cent of phosphate as pentoxide, calculated on the wet weight. These figures, 0·11, 0·13, 0·14, show that the original estimate of 0·15 per cent P_2O_5 as the phosphate content of unicellular algæ was probably fairly correct. Using it, instead of 0·2 per cent, the calculation of the algal plankton in the 70-metre column gives the result 1·4 kilogram, or $1{\cdot}4 \times 10^6$ per square kilometre.

When this result is compared with the value given as a minimum by a less exact method, the change in alkalinity of the water (Atkins, 1922), the agreement is extraordinarily close when a certain assumption is made, namely, that the carbohydrates of the algal cell, including protein carbon, calculated as a hexose sugar, amount to 15 per cent of the wet weight. This assumption was made as a consequence of Tom's figures for the total dry weight, and before the agreement was found by calculation. The alkalinity results gave an estimate of 1 kilogram per 4 square metres down to a depth of 83·3 metres. Converting this into the wet weight of algæ in a 70-metre column the value reached is 1·4 kilogram. The exact agreement is, of course, fortuitous in view of the assumptions; but it shows that the methods must have a certain degree of reliability, or rather it confirms the alkalinity result, for the phosphate method involves only one assumption, that the percentage of phosphate in the algal plankton is close to that of the larger brown algæ.

Turning now to the question of the phosphate content of marine invertebrates, according to Clarke and Wheeler (1922), only trifling quantities are, as a rule, found; certain analyses for calcareous algæ quoted by these authors are also very low, usually a trace to 0·00 per cent in the calcareous portions. The highest record is 0·18 per cent. The shells of crustacea are, however, fairly rich in phosphate, 4·07 to 6·70 per cent being the value for a medium-sized lobster, expressed as P_2O_5. Tricalcic phosphate is, indeed, the main constituent of the ash of the minute crustacea, as shown by Clarke and Salkover (1918), from which doubtless young fish obtain much of their phosphate. The shells, too, of certain brachiopods contain 75–90 per cent of tricalcic phosphate, and some worm tubes are notably phosphatic. The various amounts in the hard portions as well as in the softer tissues make it impossible to give even an approximation to the weight of invertebrates that could be produced each year.

With respect to fishes a greater uniformity is found. Atwater (1888) gives 0·514 per cent as the average value for the pentoxide of the flesh of fifty-five species. He quotes Sempolowski as giving the following figures for the phosphoric acid in the whole fish, wet weight:—

Pleuronectes limanda	1·25
Gadus aeglifinus.	1·22
Trigla gurnardus	1·78
Raia radiata	0·91
Acanthias vulgaris	0·98
Mean	1·27 per cent.
As P_2O_5	0·95 per cent.

It may be seen that the bony fishes are considerably richer in phosphate than are the cartilaginous. Seeing that they constitute by far the larger amount of fish in the sea one may take as an approximation 1 per cent of P_2O_5 for fishes in general. Now if all the phosphate used up in the 70-metre column were converted into fish it could yield each year 210 grams of fish, or roughly 1 kilogram per 5 square metres. Since there are also vast numbers of plankton and bottom-dwelling animals this is, of course, a very large overestimate; the figure yields the value 2×10^5 kilograms per square kilometre. In the absence of precise data one may perhaps assume that the fish represent between 1 per cent and 1 per thousand of this possible total quantity, which gives an estimate of between 200 and 2000 kilograms per square kilometre in water 70 metres in depth.

Methods for the Analysis of Phosphates.

Details of the usual methods where moderate quantities are involved may be found in the text-books; but their use for quantities of the order of one milligram or less per litre, reckoned as P_2O_5, involves the use of inconveniently large volumes of liquid. In precipitating with magnesia mixture the resulting ammonium magnesium phosphate is usually weighed after converting into pyrophosphate. Recently, however, Jones and Perkins (1923) have given details of a method in which the double salt may be weighed directly. Using the ammonium molybdate method of precipitation, Kleinmann (1919) has found that it is permissible to weigh as ammonium phosphomolybdate. The work of Posternak (1920) on the variability of this precipitate should, however, be remembered.

A very delicate reaction was developed by Pouget and Chouchak (1909, 1911) into a colorimetric or nephelometric means of estimating phosphates, using strychnine sulphate and sodium molybdate. The reagents produce a yellow opalescence. This has since been used by several workers, notably Kleinmann (1919), Embden (1921), who converted it into a gravimetric method, and by Matthews (1916–18). Embden found it convenient to use the resulting strychnine phosphomolybdate precipitate for work with solutions containing 1·0–4·0 mgrm. P_2O_5, since the precipitate is about thirty-nine times as heavy as the corresponding amount of pentoxide. The precipitation being performed in the cold renders this method specially suitable for the estimation of phosphate in the presence of organic phosphates, which are easily hydrolysed.

Matthews (1916–18) used the Pouget and Chouchak colorimetric method for estimating the phosphate in 500 c.c. of sea water after precipitation as ferric phosphate. The method was adopted after a very careful comparison with others available.

Raben (1916–20), working with Brandt (1916–20) at Kiel, precipitated the phosphate in 10 litres of filtered sea water by means of ferric chloride. After an elaborate purification the phosphate was determined gravimetrically as phosphomolybdate.

The results for sea water from various sources are from 51 mgrm. P_2O_5 per cubic metre in May to 221 in November. It may be said that these values are greater than those obtained by Matthews, 0·06–0·01 or less, expressed in milligrams of P_2O_5 per litre. Matthews also obtained evidence for the existence of a soluble compound of phosphorus, which can be converted into phosphoric acid by oxidising agents. The results obtained by the writer for phosphate in sea water are in complete agreement with those of Matthews, though obtained by an entirely different method. No explanation can as yet be offered as to why these differ so much from the very careful determinations of Raben and his co-workers.

A new method of great delicacy was developed by Denigès (1920, 1921), and was found by him to agree with the gravimetric method of Posternak (1920). The latter showed that the composition of the ammonium phosphomolybdate precipitate varies largely according to the proportions of the various salts present and to the temperature of precipitation; he accordingly worked out a process in which a barium phosphomolybdate of constant composition may be obtained.

Method of Denigès for Phosphates.

Two reagents are required for the "cœruleomolybdic" method of Denigès: (*a*) 10 per cent ammonium molybdate and pure sulphuric acid in equal parts by volume, and (*b*) stannous chloride, freshly prepared from 0·1 grm. of tin dissolved in 2 c.c. of hydrochloric acid with one drop of 3–4 per cent copper sulphate and made up to 10 c.c. On mixing a few drops of (*a*) with 10 c.c. of the liquid to be tested and adding one or two drops of (*b*), an intense blue appears in the presence of phosphate. Denigès employed this reaction for the analysis of biological products, but it was used in a slightly different form by Florentin (1921) for the determination of the phosphate content of fresh waters. Denigès considers that the maximum delicacy of the method is for solutions containing 0·5–10 mgrm. of phosphorus as phosphoric acid.

Florentin has employed it for the estimation of phosphate equivalent to 0·01–5·0 mgrm. of P_2O_5. He makes up solution (*a*) with 100 c.c. of 10 per cent ammonium molybdate plus 300 c.c. of 50 per cent (by volume) sulphuric acid. For analysis 10 c.c. of water is taken, to which are added three or four drops of (*a*) and one drop of (*b*), or three drops of (*b*) if more than 2 mgrm. of P_2O_5 is present. The blue colour developed reaches its maximum in less than ten minutes. Comparison is then made with standards containing known amounts of phosphate, or indigo carmine for greater permanency. The acidity prevents the production of blue with molybdate alone. According to Florentin more than 0·1 grm. per litre of Na_2SiO_3 gives a colour. As shown in an accompanying paper by the author no such amount of silicate has been found in any of the natural waters examined, for which 0·006 grm. per litre SiO_2 (or 0·012 grm. approximately of silicate) is a high value. H_3AsO_4 gives a blue colour similar to that given by phosphate, so any traces present are included in the phosphate estimation.

The writer has made use of the reagents according to Florentin's formula for (*a*), and has found it advisable to use 100 c.c. of the water to be tested owing to the minute traces of phosphate present. To this quantity of fresh or sea water 2 c.c. of (*a*) are added and five drops of (*b*), and the blue tint is examined in a graduated 100 c.c. cylinder with

a tap near the base. The tint is compared with that given by a convenient strength of phosphate solution, usually one containing the equivalent of 0·05 mgrm. of P_2O_5 per litre. The standard solution falls off somewhat on keeping; a 6 per cent decrease was observed in $2\frac{1}{2}$ hours, by comparison with a fresh solution. This amounts to 1 per cent per half-hour approximately, so when examining a series a fresh standard is mixed after about half an hour. Taken over a twenty-five hour period, however, the decrease was only 1 per cent per hour. Sometimes the solutions quickly develop a turbidity. This trouble has been traced to the stannous solution, which is apt to give the precipitate if added to the sample before the acid molybdate, or if added in too great amount, or if heated for an undue length of time when being prepared. It was, moreover, noticed that the precipitate came more readily in distilled or naturally occurring fresh water than in salt water, in which the sodium chloride apparently lessens hydrolysis by diminishing the percentage ionised.

When adjusting the height of the stronger solution to match that of the lighter at the 100 c.c. level the columns are viewed standing on a thin glass shelf below which is opal glass. The sides and back of the stand are black. Accuracy is assisted by having on the opal glass a white card on which are ruled black lines. This is adjusted so that half of the field of each column is occupied by the card, and half by the opal glass. The tubes are screened in front by cardboard.

Before trying the cylinders, which are now used invariably, Nessler tubes containing 50 c.c. were used; a series from 0·05–0·01 mgrm. P_2O_5 was made up, and it was found that the members could readily be arranged in the correct order. The use of the cylinders increases the accuracy, as it is usually possible to get duplicate readings to within 2 c.c. on the column. Good agreement may also be obtained against a standard of a different strength. Thus sea water tested against a 0·05 standard gave :—

1st reading 66, viz. $\frac{0{\cdot}05 \times 66}{100} = 0{\cdot}0330$ mgrm. P_2O_5 per litre.

2nd reading 67·5 $= 0{\cdot}0337$,, ,, ,,

Against a 0·04 standard the reading was 82, corresponding to 0·0328 mgrm. P_2O_5 per litre. The colour is not sufficiently intense with such dilutions to permit of the use of the Duboscq colorimeter, on account of the shorter length of liquid column available.

There is, however, one source of error which remains as yet quite unexplained. On standing with the reagents sea water and certain fresh water samples from ponds develop a slight yellowish tint. This is not noticeable as a rule till after five minutes, so the comparison should be made before it has time to develop, and as soon as the blue has reached its

maximum intensity. The colour is not given by the acid molybdate alone. An exact match may nevertheless be obtained even in the presence of the yellow tint by adding drops of very dilute Bismarck brown to the standard. The result got by trying to match the tints without the addition of the brown is usually about 0·004 mgrm. per litre too low.

It must be added that blank estimations are made from time to time by adding the reagents to distilled water. With freshly made up molybdate mixture no more than 0·0005 mgrm. per litre need be subtracted for the tint given by the reagents, 0·002 mgrm. is a very usual value for molybdate mixture stored in the dark, and after some time in the light as much as 0·004 mgrm. may have to be deducted.

It should be stated that the standard phosphate solutions were made up by diluting a solution of sodium ammonium hydrogen phosphate equivalent to 5 mgrm. P_2O_5 per c.c. The stock solution was diluted to give 50 mgrm. per litre, and for general use this was further diluted to 0·5 mgrm. per litre. By taking 10 c.c. of this and making up to 100 c.c. the usual standard 0·05 mgrm. P_2O_5 per litre was obtained. Solutions not conveniently matched against this strength were either diluted suitably or else a more concentrated standard was used. Such solutions are very liable to grow moulds or minute green algæ, which, of course, alter their phosphate content. The addition of a little toluene was, however, found to prevent this for some months at any rate.

It is also noteworthy that Florentin pointed out that the presence of the acid prevents the molybdate alone from giving a blue with stannous chloride. On one occasion through an error the acid molybdate solution was made up to contain only 25 per cent of sulphuric acid; as usual 2 c.c. of this was added to 100 c.c. sea water, followed by five drops of stannous chloride. The intense blue which developed appeared to denote an absurdly large phosphate content, and on repeating the estimation with fresh reagents the mistake was discovered and Florentin's observation was recalled to mind.

As previously mentioned it is possible to get readings in duplicate, when comparing the blue tints in the 100 c.c. cylinders, which agree to 2 c.c. This limit, using a 0·05 mgrm. P_2O_5 per litre standard, corresponds to 0·001 mgrm. per litre. Even taking it that the reading may be 2 c.c. too high or too low, the error only becomes $\pm$0·001 mgrm. per litre. This should not be surpassed in clear solutions in which no yellow tint develops. With slightly turbid solutions or those which are tinted the error may, of course, be greater, though use of dilute Bismarck brown materially reduces it. Matthews, using Pouget and Chouchak's method on the phosphate from 500 c.c., considers that the estimation is accurate to about 0·003 mgrm. per litre. The method of Denigès, as used by the writer, gives results which are in most cases accurate to $\pm$0·001 mgrm.

per litre, and may certainly be considered at least to equal those obtained by the Pouget and Chouchak method in accuracy. Furthermore, since the method of Denigès requires only 100 c.c. the phosphate actually estimated is only one-tenth of the concentration in milligrams per litre.

Matthews found that, using filtered sea water, duplicate determinations required five hours. The filtration, moreover, took upwards of sixteen hours, and was necessary on account of the risk of contamination of the precipitate. Using the method of Denigès an estimation occupies ten minutes, and unless particles of phosphate are suspended in the liquid no error results from the presence of the ordinary amount of algal plankton. It must be concluded that this mode of estimation has many advantages.

It may be added that to convert the conventional P_2O_5 values into the more rational values for the PO_4 ion the factor 1·338 may be used to multiply the former. The factor is very approximately $\frac{4}{3}$. For the converse the factor 0·7474 should be used, which may be taken as $\frac{3}{4}$.

SUMMARY.

1. The phosphate content of uncontaminated streams and fresh water supplies examined was under 0·05 parts per million reckoned as P_2O_5. To convert to PO_4 the factor 1·338, very approximately $\frac{4}{3}$, may be used.

2. A pure culture of *Nitzschia closterium* W. Sm., in sea water enriched with Miquel's solution, multiplied in numbers up to over three million per cubic centimetre, when the phosphate was all used up. It was ascertained that 1·12 mgrm., expressed as P_2O_5, is required for the production of 1×10^9 diatoms during the early stage of the culture. One gram of the pentoxide suffices for 9×10^{11} diatoms.

3. Sea water insolated in the Laboratory decreases rapidly in phosphate till none is left. Samples taken in winter show a less rapid decrease than those taken in spring. This is due to their smaller content of algal plankton. Ferric chloride removes phosphate from sea water or culture solutions very completely.

4. The phosphate content of sea water falls from a value of 0·036 mgrm. per litre at the surface at Station E1 in March to zero in July. The bottom value also falls to 0·011 mgrm. in July, so that there is a consumption throughout the column of water to 70 metres of 0·030 mgrm. per litre. Similar changes take place in Plymouth Sound and at the Hydrographic Stations E2, E3, and N1–N3. The surface water is almost free of phosphates from May to August.

5. A few determinations made indicate the same seasonal change in the North Sea. The deep water off the Norwegian coast acts as a reservoir of phosphate, which presumably gets depleted during summer; 0·036 mgrm. per litre was found there on May 6th at 280 metres. The North Sea values for phosphate are much lower than those found by Raben, and the phosphate analyses in general agree well with the results obtained by Matthews. As regards the seasonal change the results are in agreement with both workers.

6. The phosphate of fresh water ponds was found to fall almost to zero early in April, and to continue low throughout summer.

7. An estimate may be made of the total algal plankton crop each year, using the figures recorded in §2 and §4 of this Summary. Since 1·12 mgrm. of P_2O_5 suffices for 1×10^9 diatoms, each litre of sea water could produce 26·8 million diatoms for a consumption of 0·030 mgrm. As many as 30 million diatoms per litre were found by the writer in a fresh water pond, so these large figures, as calculated, need not seem impossible.

Taking it that each cubic metre to a depth of 70 metres loses 30 milligrams of phosphate as P_2O_5 and that the phosphate content of the algal plankton is 0·15 per cent, calculated on the wet weight, it results that the column of water produces 1·4 kilograms algal plankton per square metre of sea. If one assumes that the carbon content of the algæ, reckoned as a hexose sugar, amounts to 15 per cent of the wet weight the calculation made by the writer (1922) from the seasonal change in alkalinity gives an identical value 1·4 kilograms. The exact agreement is fortuitous, but it lends support to the validity of the alkalimetry method.

8. The colorimetric method of Denigès was found very convenient for the analysis of waters containing 0·050 to 0·001 mgrm. of P_2O_5 per litre. An accuracy of $\pm$0·001 mgrm. can be obtained in clear solutions free from tint, and results to within $\pm$0·002 may readily be obtained. For samples which develop a yellowish tint with the reagents it is convenient to add a little Bismarck brown to the standard.

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Note.—Up to the end of November, 1923, the phosphate content of the fresh waters studied has been far below the 1922 values, obtained on stored samples. This indicates that the possible error from storage, mentioned on p. 140, l. 1–3, may be very considerable. The accuracy of Fig. 8 is thus impaired.

The Silica Content of some Natural Waters and of Culture Media.

By

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WHEN studying the seasonal changes in the algal plankton in relation to the supply of the constituents necessary for their growth, one is led to seek the source of the silica used to form the valves of the diatoms and to consider whether lack of silica might be a factor limiting their multiplication.

Since water is collected and stored in glass vessels it is also necessary to consider how far the latter act as sources of silica which may lead to erroneous results, both in analytical examination of samples and in culture experiments.

Accordingly, the silicate, reckoned as SiO_2 was estimated in natural waters as shown in Table 1 (page 152). The " chloride " bottles mentioned are the usual ones as supplied for sampling sea-water. They are of green glass with porcelain stopper and rubber ring, closed with a metal spring clamp, and are of about 170 c.c. capacity. The Winchester quart bottles are of light green glass.

SILICA CONTENT OF FRESH-WATER.

The figures in Table 1 do not appear to indicate any appreciable rate of solution of the silicate of the bottles, for the lowest value, 0·48 for Maryfield pond, was obtained on a sample which had stood for two months in the bottle. The difference between this minimum value and the ones which come before and after it seems remarkable, and on turning up some quantitative estimations of the algal plankton it was seen that whereas on 15th of April the pond contained roughly 15,000 diatoms per cubic centimetre, on 24th there were 27–32,000 and a Chlamydomonas surface scum in parts. On May 6th diatoms had greatly decreased, being apparently under 1000 per c.c., and an Euglena scum was starting to develop. This increase in diatoms, corresponding with a decrease in

silica, suggests an explanation of the low value for the latter. In view, however, of the fact that the method, as used in the estimation in question, is incapable of detecting much less than 0·2 mgrm. of SiO_2, the observation needs confirmation.

The highest values for silica, 6·25 mgrms, is given by the Basingstoke town supply, which comes from deep wells in chalk, whereas the Plymouth

TABLE 1.

FRESH-WATER.

Source of Sample.	Collected.	Examined for Silica.	Type of Bottle.	Electrical Conductivity at 0° C., $\times 10^6$.	SiO_2 in milligrams per litre.	pH.
Maryfield quarry pond	15/4/23	22/6/23	chloride	161	0·76	8·7
,, ,,	24/4	,,	,,	170	0·48	8·6
,, ,,	6/5	,,	,,	182	0·68	8·6
,, ,,	2/6	,,	,,	190	1·04	8·5
,, ,,	17/6	20/6	,,	200	1·30	8·2
,, ,,	24/6	25/6	,,	192	0·94	8·2
,, ,,	30/6	2/7	,,	196	0·92	8·0
Staddon reservoir	3/4	22/6	,,	244	4·2*	8·4
,,	1/5	22/6	,,	204	4·0*	8·3
,, (inlet)	1/5	22/6	,,	270	2·88	—
,, (inlet)	23/6	23/6	,,	270	3·30	—
,,	23/6	23/6	,,	238	2·4†	7·95
,,	29/6	29/6	,,	208	1·76	8·6
,, (inlet)	29/6	29/6	,,	270	3·28	6·65
,, (inlet)	26/7	1/8	,,	287	6·25	6·65
,,	26/7	1/8	,,	204	3·45	8·7
Basingstoke tap	23/6	25/6	,,	270	6·25	7·2
Maryfield tap	24/6	25/6	,,	270	4·44	7·2
Plymouth tap	21/6	21/6	From pipe	25	3·33	6·4

tap from Burrator Reservoir on Dartmoor, a granite area, has only about half the quantity, 3·33 mgrms. The latter, however, constitutes a relatively higher proportion of the total solids, as shown by the electrical conductivity measurements. Maryfield tap supply comes from a Staddon Grits catchment area in the Lower Devonian Series, on which the Staddon

* Water had brownish tint. † Slight tint.

reservoir—a cemented tank fed in dry weather only by an inlet pipe—is also situated. This in the July drought equalled the high Basingstoke value. The Maryfield quarry pond lies on Upper Devonian Slate. It appears that some cause must be active in removing silica from the water of the ponds, which show lower values than the spring waters.

It is to be noted that the tap water at pH7·2 is in each case rich in calcium salts, and becomes more alkaline as excess of carbon dioxide passes off into the air ; thus one would expect it to be a better solvent for silica as its pH value rises, hence the lesser content of silica in the ponds is not due to a chemical precipitation occasioned by increasing alkalinity. This again points to the removal of silica by a biological agency, for example, by diatoms.

In view of the work of Thresh (1922) upon the importance of the silica content of town supply water in reducing the action of oxygen upon lead, the action of diatoms becomes of increased interest, especially as their great abundance at certain periods might cause seasonal changes in the plumbo-solvency of water supplies. Thresh found that the water of Loch Katrine with only 0·1 mgrm. per litre SiO_2 had the greatest action upon lead of any source examined.

SILICA CONTENT OF SALT-WATER.

The electrical conductivity and pH values have been omitted from Table 2 (page 154), as the sea water is of almost identical salinity at all the stations examined and the pH value was at 8·1–8·2.

The analyses appear to indicate a decrease in silica content as summer is approached, and such a decrease must occur almost certainly in view of the minute amount available. The figures given do not, however, prove this, on account of the possible solution of traces from the glass. Assuming that the value 0·2 mgrm. for June 25th is correct, the Winchester filled in December appears to have been enriched with SiO_2 by 0·2 mgrm. per litre per month, and the May Winchester by 0·35 for one hot month.

On the other hand, there is no evidence that one month in chloride bottles has resulted in any silica going into solution when stored in the dark, and over a seven-month period the amount dissolved cannot have exceeded 0·06 mgrm. per litre per month, even were the water no richer in silica in winter than in summer. It seems, therefore, that t is quite permissible to use chloride bottles to convey sea water from the hydrographic stations to the Laboratory for immediate analysis, namely, for storage of up to five days, for this could not increase the silica content by more than 0·01 mgrm. per litre.

TABLE 2.

Salt-water.

Source of Sample, Hydrographic Station.	Collected.	Examined for Silica.	Type of Bottle.	SiO_2 in milligrams per litre.	How stored.
E1, 0 metres	9/11/22	22/6/23	Chloride	0·62	In dark
E1, 70 ,,	,,	,,	,,	0·60	,,
L6, 0 ,,	18/12/22	,,	,,	0·52	,,
L1, 0 ,,	,,	,,	,,	0·50	,,
E1, 0 ,,	,,	,,	Winchester	1·4	In sunlight
E1, 0 ,,	16/1/23	,,	,,	0·42	,,
E1, 0 ,,	,,	,,	Chloride	0·39	In dark
E1, 50 ,,	,,	,,	,,	0·35	,,
E1, 25–60 ,,	10/7/23	4/8/23	,,	0·19*	,,
N1, 0 ,,	23/5/23	22/6/23	Winchester	0·55	In light
N1, 0 ,,	,,	,,	Chloride	0·15 or less	In dark
N1, 50 ,,	,,	,,	,,	0·17 ,,	,,
N1, 75 ,,	11/7/23	12/7/23	,,	0·15 ,,	,,
N1, 0–95 ,,	11/7/23	1/8/23	,,	0·38*	,,
L6, 0 ,,	19/6/23	22/6/23	,,	0·17 ,,	,,
L6, 63 ,,	,,	,,	,,	0·17 ,,	,,
L2, 0 ,,	,,	,,	,,	0·23 ,,	,,
L2, 12 ,,	,,	,,	,,	0·15 ,,	,,
Laboratory sea-water reservoir	26/6/23	,,	—	0·55†	—
Diatom culture filtered, culture started 17/3/23	—	,,	—	0·55	
East slip, below Laboratory	25/6	25/6	Carried in jar	0·21‡	—
Eddystone W.S.W. 4 miles, near L4	2/7	2/7	Chloride	1·06‡	—

* 500 c.c. evaporated to 100 c.c. in platinum dish.

† Possibly too high, owing to high phosphate content of this sample.

‡ 400 c.c. evaporated to 100 c.c. in platinum dish.

It appears that the value 1·06 mgrm. for July 2nd is abnormally high, and may have resulted from the solution of particles of some source of silica during the evaporation, possibly of diatoms. That some silica has gone into solution during the evaporation is also indicated by the values for Station N1 on July 11th. Here a determination on the untreated 75-metre sample showed 0·15 mgrm. or under, whereas on evaporating 500 c.c., made up of portions of samples from surface to bottom, 0·38 mgrm was obtained. In this and the corresponding E1 sample 500 c.c., made up of portions of samples from surface to bottom, the salt incrustation in the platinum dish was dissolved, and the silica retained, if any, added to that in the salt water. Thus for N1 the latter amounted to 0·132 mgrm., and the incrustation contained 0·060 mgrm. No silica could, however, be detected in the incrustation of the E1 sample.

Brandt (1920) has recorded a seasonal change in the water of the Baltic as regards silica, 900 mgrms. per cubic metre (or 0·9 mgrm. per litre) in February having diminished to 600 mgrms. in May. This was followed by a rise in June. Bottom water was somewhat richer, 1150 mgrms. having been found in February. As the Baltic is altogether surrounded by land it seems reasonable that its silica content should be somewhat higher than that of the English Channel, for the fresh waters examined by the writer are all richer in silica than is the sea. Furthermore, it was found that by shaking up one part of air-dried soil (which passed a sieve of one hundred meshes to the inch and gave a reaction of pH7·8) with five of water, after eleven days the resulting solution contained 13·2 mgrm. of silica per litre.

ACTION OF DISTILLED AND OF SALT-WATER UPON GLASS.

In order to test the action of water upon glass vessels such as were, or might be, used for diatom cultures, the following were tested by filling them about half full of distilled water and leaving them for two hours on a boiling-water bath, after which they stood for a day. It was then found that a small flask of English glass, used by Dr. E. J. Allen for diatom cultures, a litre flask of English R glass, also used for cultures, a Moncrieff conical flask, 350 c.c., a Jena litre flask, and a Kavalier S, 500 c.c. conical flask were so insoluble that the distilled water showed a conductivity of less than 0·000,01 at 0° C., the lowest measurable with the cell used. On further testing the Jena and Kavalier vessels with a cell of lesser resistance the Jena glass showed the limiting value 0·000,001 and the Kavalier 0·000,002. It may be added that the purest water obtainable in contact with atmospheric carbon dioxide has a

conductivity of 0·000,000,7, and Lehfeldt (1908) gives 0·000,005 as the maximum allowable in water used for conductivity work, though 0·000,001 is usually required for research work. Colorimetric measurements of hydrogen ion concentration also showed that these vessels had maintained the distilled water at below pH6, so they may all be considered as highly resistant to the action of pure water. Before applying the foregoing tests they were all proved to contain less than 0·2 mgrms. per litre of SiO_2, which is the limit for the method without concentrating the water. Subsequently a Kavalier B conical flask, an unmarked conical flask, and a Swedish Reijmyre special glass beaker were similarly shown to contain no measurable amount of silica in solution, but they were not submitted to the other tests.

The vessels were then filled as before, and heated for three hours, but with sea-water instead of distilled water. The sea-water contained under 0·2 mgrms. per litre of SiO_2 at the start, and after the treatment various amounts of silica from 1·7 up to 5·7 mgrms. per litre were found, the average for the eight vessels being 3·7 per litre. Since the vessels were of diverse shapes, unequal areas were exposed, so truly comparable results cannot be given. It seems accordingly that in time even these highly resistant glasses must give up to sea-water the small amounts of silica required in diatom cultures. This has been proved by Richter (1904), who showed that using vessels coated with paraffin wax, abundant diatom cultures could not be obtained. The culture medium used by Dr. E. J. Allen consists of sea-water enriched by Miquel's solution (1910), and then heated to boiling. The water of such a culture of *Nitzschia closterium*, which had multiplied to the extent of over three millions per cubic centimetre, was filtered through paper, and no diatoms were to be seen in the uncentrifuged filtrate. The latter was then found to contain 0·55 mgrms. per litre of SiO_2 in solution, so it is evident that either during the boiling or subsequent standing, or during both together, a considerable amount of silica must have become available. The figure given may possibly be high, owing to phosphate in the solution also. It may be added that the boiling of sea-water increases its alkalinity up to pH10, and diatom cultures exposed to a good north light become nearly as alkaline, pH9·6 having been observed. As compared with distilled water at pH6, sea-water at pH8 contains one hundred times as great a concentration of hydroxyl ions, and at pH10 the concentration is again increased an hundredfold, namely, ten thousand times in all, so it is not surprising that silica should go into solution far more readily than in distilled water.

As regards the sources of silica for diatom cultures the work of Coupin (1922) is of interest. He found that whereas Knop's solution made up with one per cent gelose gave no growth of *Nitzschia linearis* without

any form of silica, or with gelatinous silica or washed vitreous silica (Fontainebleau sand), yet a splendid growth was obtained when washed kaolin was sprinkled on the surface of the medium. Powdered feldspar also gave a good growth, part of this mineral being altered to kaolin. Pure clays were found to act like kaolin, but potassium and sodium silicates gave no growth or even killed the diatom, nor did powdered glass on the surface lead to any growth. The results were confirmed in celluloid dishes. Coupin concluded that diatoms obtain the silica they require from silicates of aluminium. Just prior to this Vernadsky (1922) had shown that a species of Nitzschia obtained from moist earth could grow well in cultures provided with kaolin, and could decompose clay with liberation of free aluminium hydroxide. Bacteria were also present in the cultures. Murray and Irvine (1891) had previously invoked the presence of particles of clay in sea-water as a source of the silica required by diatoms.

METHOD OF ESTIMATION OF SILICA.

The analyses recorded in this paper were carried out by the colorimetric method of Diénert and Wandenbulcke (1923). For this two reagents are required, a 10 per cent solution of ammonium molybdate, and a 50 per cent (by volume) solution of sulphuric acid. For each 100 c.c. of water to be tested 2 c.c. of molybdate and four drops of acid are added. A yellow colour develops, and reaches its maximum in less than ten minutes, after which it remains constant for some time. The directions given by Diénert and Wandenbulcke are to add four drops of acid to 50 c.c. On adding eight to 100 c.c. it was, however, found that a blue tint was apt to develop, which was difficult to match against picric acid, though the normal yellow tint could be matched exactly. This difficulty was at first overcome by adding a trace of methylene blue to the standard picric acid. Using 100 c.c. of distilled water, 2 c.c. of ammonium molybdate at pH5·3, and eight drops of acid, the resulting mixture was found to be at pH1·6, and in this a blue colour developed with the yellow. With twelve drops pH1·4 was reached and with sixteen pH1·25, the blue becoming increasingly stronger. However, by using only four drops of acid in sea-water a clear yellow was given at pH2·15. The reaction of the mixture should therefore lie close to pH2, for if the pH value is higher no yellow colour appears, and if lower the blue tint gives a resultant greenish shade. The authors named recommend that comparisons should be made against picric acid to afford permanent standards, and find it convenient to make up a solution containing 36·9 mgrms. per litre of picric acid as giving a yellow corresponding to that given by 50 mgrms. of SiO_2 per litre. This was diluted by the writer

to give standards equivalent to 2·0 and 0·5 mgrms. SiO_2 per litre. Comparisons were made in 100 c.c. graduated cylinders, provided with taps near the base. By this means it was possible to distinguish a faint yellow tint using the 0·5 standard at the level of 40 c.c.—or possibly 30 c.c., which corresponds to detecting 0·2–0·15 mgrms. per litre of SiO_2. The figures given in the second decimal place in the tables are, therefore, of uncertain significance. The use of a light blue glass was found helpful in judging these faint yellow tints. With sea-water it was necessary to concentrate the liquid by evaporating to one-fourth or one-fifth in a platinum dish, but the crystallisation of the salts is a source of trouble and prevents further concentration. Traces of silica in suspension are liable to be dissolved during the evaporation.

SUMMARY.

1. There are indications of seasonal changes in the silica in solution in fresh-water ponds, which cannot be explained by the mere dilution or concentration of the solutes in general; they appear rather to be due to the action of diatoms. A minimum value of 0·5 mgrms. of SiO_2 per litre in April rose to a maximum of 1·3 in June in one pond.

2. It is also probable that the silica content of sea-water undergoes similar seasonal changes, but the fact that traces of silica from the bottles had gone into solution during storage renders this uncertain. Sea-water in June was found to contain 0·2 mgrm. SiO_2 per litre, or somewhat less.

3. Pipe supplies were found to contain from 3·3–6·2 mgrms. SiO_2 per litre, lesser values found in two ponds appear to suggest the removal of silica by diatoms.

4. The walls of resistance glass vessels were found to give off no measurable amount of silica to distilled water, but boiling for three hours with sea-water increased the silica content of the latter by from 1·5–5·5 mgrms. per litre. Apparently the higher alkalinity of the sea-water, which is raised still further by boiling, or by photosynthesis in diatom cultures, favours the solution of the silica.

5. The method of Diénert and Wandenbulcke has been found sensitive enough to estimate silica down to a limit of 0·2–0·15 mgrms. per litre without concentrating the solution. The liquid under examination should, after adding the reagents, be close to pH2.

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Note on the Oxidisable Organic Matter of Sea Water

By

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In a former paper (1922) it was shown that the pH value of stored sea water decreased owing to the production of carbonic acid by organisms in it, and the oxidisable matter as indicated by this biological method appeared to be higher than the result obtained by oxidation with permanganate, according to various analyses available for comparison. These, however, were not done on the same water, so an attempt was made to determine this quantity on water of the English Channel off Plymouth. As is well known the permanganate method gives results which vary appreciably, according to the conditions of the experiment.

The standard method of the Public Health Association of the U.S.A. was adopted, with a slight modification necessary for its use with sea water. The solutions required are as follows :—

1. One volume of pure sulphuric acid diluted with three of distilled water. To this dilute potassium permanganate is added till a faint pink persists after standing for several hours.

2. Pure dry sodium oxalate, 0·959 grm. per litre, giving 1 c.c. equivalent to 0·1 mgrm. of oxygen ; the solution was preserved with toluene. (The standard method is to take 0·888 grm. of ammonium oxalate, without preservative.)

3. Permanganate solution, 0·4 grm. per litre. This was allowed to stand in a warm place for over a fortnight to oxidise traces of organic matter. A more stable solution is thus obtained. To standardise the permanganate the procedure is as follows :—

10 c.c. sulphuric acid, 10 c.c. permanganate and 100 c.c. of freshly distilled water are placed on a boiling water bath for thirty minutes in

a chemically clean, conical flask of hard glass; 10 c.c. of sodium oxalate are then added, followed by permanganate till a faint pink persists in the hot liquid for several minutes. This treatment destroys the oxygen-consuming capacity of the water. After adding 10 c.c. of sodium oxalate, permanganate is run in till a faint excess persists; duplicate determinations gave 11·47 and 11·49 c.c. of permanganate, and the latter value was adopted, no attempt being made to adjust exactly to 10·0 c.c., since it is necessary to restandardise at intervals. The above permanganate solution is accordingly equivalent to 0·087 mgrms. of oxygen per c.c.

When the water contains appreciable quantities of chloride, as in some sewage effluents, the official method is to digest in alkaline solution, instead of in acid, to avoid evolution of chlorine. For this purpose 10 c.c. of permanganate is added to 100 c.c. of the sample, followed by 0·5 c.c. 50 per cent sodium hydroxide. After digestion as before for thirty minutes 5 c.c. of sulphuric acid and 10 c.c. of oxalate are added, and the latter is titrated back with permanganate. Plymouth tap water tested by acid and alkaline oxidation was found to absorb 1·65 and 1·63 milligrams of oxygen per litre respectively, figures which may be considered identical. The newly distilled water took 0·64 mgrms., and a fresh-water pond fairly rich in algæ absorbed 3·34 mgrms.

Considerable difficulty was experienced in applying either method to sea water, and a number of determinations had to be rejected. It is impossible to use the acid oxidation on account of evolution of chlorine. With the alkaline method, as laid down, 5 c.c. of sulphuric acid is added, followed by the standard oxalate to destroy permanganate, excess being titrated back as before. This gives consistent results even when the chloride is as high as one per thousand, viz. 5 c.c. of sea water made up to 100 c.c. with distilled water, but the method is then of insufficient delicacy to detect with certainty the small differences met with in sea water from place to place. With undiluted sea water it is however unreliable, owing to evolution of chlorine, which is readily detected by its smell.

An attempt was made to omit the addition of acid, but in alkaline solution the reaction between permanganate and oxalate proceeds with surprising slowness even at boiling point. Consistent results may, however, be obtained as follows. After digestion 10 c.c. of the oxalate are added immediately to the alkaline solution and the acid is added in small portions while the liquid is kept in rapid rotation; when the colour has disappeared the permanganate from the burette is added with all speed to the moving liquid, and if overshot a duplicate may be done. The end point taken is the persistence of the pink for about a minute.

Estimations carried out as described gave the results shown below :—

Station E1, 10 m. S.W. of Eddystone, taken 12/3, stored 7 days	1·00
Same sample, filtered through Doulton candle	2·37
Near Eddystone, taken 7/3, stored 12 days, filtered through Doulton candle	1·97
Same sample, stored 25 days, cleared with a few drops of ferric chloride and filter paper	0·76
Near Eddystone, taken 8/3, stored 11 days	0·84
,, ,, ,, 21 days	1·08
,, ,, ,, 21 days and hydrolysed for one hour at 100° C. with 10 c.c. N/10 H_2SO_4 per 100 c.c. sea water	2·12
Culture of *Nitzschia closterium*, 510,000 per c.c.	3·10
Ditto, but digested for 80 minutes instead of 30	4·78

The values obtained with untreated sea water after half an hour's digestion are approximately the final values, as prolongation to one hour only resulted in an extra 0·1 c.c. of permanganate being absorbed. It is clear that much of the organic matter exists in a form in which it is not readily oxidised by permanaganate, since higher values are obtained on storing and after hydrolysis ; also it is obvious that the water at E1 in March cannot contain anything approaching 100,000 diatoms per c.c., as one would infer were the organic matter measurable by the oxygen absorption.

No method has as yet been used for estimating the oxygen absorption apart from the suspended organic matter, including living organisms, but it is hoped that this may be done by means of the Sharples super-centrifuge. The figures given show that the Doulton filter candle, after a considerable amount of washing, contaminated the water, but treatment with ferric chloride, which gives a precipitate in sea water, appears worth further trial.

SUMMARY.

1. Oxidation with alkaline permanganate and titration, according to the method of the American Public Health Association, can be used to estimate the oxygen absorption of water containing one part of chloride per thousand, but not of sea water.

2. By adding the oxalate solution to the hot alkaline permanganate after digestion and then acidifying cautiously, with the liquid in rapid rotation, it is possible to work with undiluted sea water if the final titration be also made with all speed.

3. The water of the English Channel in March absorbs about one milligramme of oxygen per litre, the amount being increased somewhat by storing the water, also by hydrolysis of the algal plankton with dilute acid.

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Animal Communities of the Level Sea-bottom in the Waters adjacent to Plymouth.

By

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With 1 Chart, and 6 Figures in the Text.

From May, 1922, onwards the $\frac{1}{10}$ sq. metre bottom-sampler has been used to collect samples of the bottom-deposits with their animals, in the waters off Plymouth. The animals have been removed as soon as possible after capture by passing the samples through a series of sieves, and have been preserved in alcohol, to be identified and counted ashore. The present report deals with the distribution of the species represented, in the light of Petersen's Community investigations in Danish waters.

I express my thanks to Dr. Allen, Dr. Orton, Mr. Hunt, and Mr. Smith, of the Plymouth Laboratory, for their kind help in the identification of the material. I am particularly indebted to my friend, Mr. R. Winckworth, a late member of the staff, who has not only gone over with me the bulk of my collection of lamellibranchs, but has provided me with an excellent type series as complete as the material would allow.

The extensive use of his bottom-sampler in Danish waters and elsewhere has enabled Dr. C. G. Joh. Petersen to advance an opinion that "*as a rule it is best to regard the animals living on the sea-bottom as communities, just as botanists group together the vegetation of the land into plant communities, even though in the present state of our knowledge it is impossible to show how intimate the mutual relations are between the animals of the sea in the single cases.*"

It will probably assist the reader if I commence with a short summary recalling the more important points, concerning the recognition of communities, which have been advanced by Petersen, and in doing so I shall adhere closely to his own words.

When dealing with animal life on the sea-bottom distinction must be made between two classes :—

(i) The animals of the level sea floor which, with the exception of the predatory species, live as a rule buried in the bottom.— The Fauna of the Level Bottom or Infauna.

(ii) The animals which live upon or are attached to other objects.— The Epifauna.

The animals taken in the bottom-sampler from the Level Bottom are not of equal importance either for characterisation of a community as such, or for characterisation of the outer conditions on which the existence of that community is dependent. Some species are *seasonal*, only occurring in quantity at certain times of the year ; others, which may be regarded as *attendant species*, may be found at greatly varying depths and in very different communities, often in considerable numbers ; others occur so sparsely in the hauls that they must be considered as being so scarce that they only exceptionally come into the small areas investigated, and no importance can therefore be attached to their absence or presence. *The animals which are not seasonal, and which compose an important part of the whole mass of a community, owing to number or weight, will presumably be best suited for characterising the community and must also be considered as giving a good idea of the outer conditions on which the community is dependent.* It necessarily follows, then, that only by experience gained from different places can these *characteristic species* be determined. A limited number of the characteristic species may be selected quite arbitrarily, and their names, or convenient abbreviations, utilised for the naming of the animal communities for which they are characteristic. By means of some 10–12 such species, Petersen has enumerated 9 communities on the level bottom in Danish waters (6, page 13) ; but for present purposes attention may be restricted to 5 of these :—

1. The **Macoma** or Baltic community, d.

   Macoma baltica, d, *Cardium edule*, *Mya arenaria*, and *Arenicola marina* are the most evenly distributed species.

2. The **Abra** community, b ± E.

   Abra alba, b, is the main characteristic species, but at times *Macoma calcarea*, c, and *Astarte* sp. a, may be present in great numbers. *Echinocardium cordatum*, E., as the signs indicate, may be present or absent.

3. The **Venus** community, v ± E.

   Characterised by *Venus gallina*, *v*, *Tellina fabula*, and several other allied sand-dwelling lamellibranchs. As in 2, *Echinocardium cordatum* may be present or absent.

4. The **deep Venus** community, (v).

   Related to 3, but *Echinocardium cordatum* is replaced by *E. flavescens*, and *Spatangus purpureus*, while *Psammobia faerœnsis*, *Abra prismatica*, and *Mactra elliptica* occur. This community is only feebly represented in Danish waters, and has not therefore received such detailed attention as the remainder.

5. The **Echinocardium-filiformis** community, E. fil.

Echinocardium cordatum, E., and *Amphiura filiformis* fil., are the leading species, but *Turritella terebra* T, is very often present. Indeed, in the earlier work Turritella was utilised instead of *Amphiura filiformis* for the descriptive name of this community.

The occurrence of these communities is dependent on the depth and degree of shelter and enclosure of the water area (5, page 9) :—

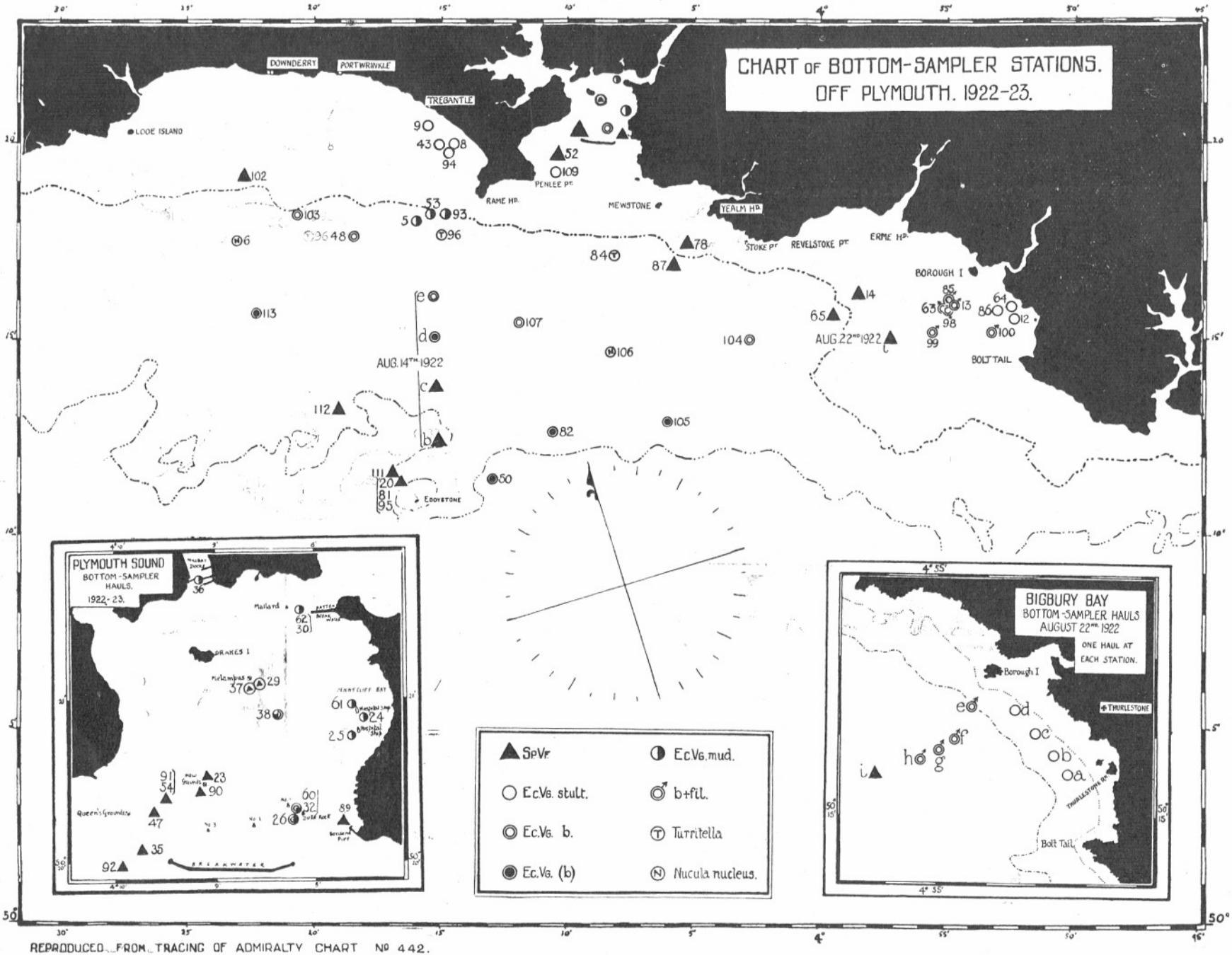
In the MORE SHELTERED waters, d communities occur nearest to land, which may be followed by v, or E.v, although frequently these last-named animals may be outnumbered by *Abra alba* b, or *Macoma calcarea* c, and in the Danish Belts and Western Baltic, by the Astarte species a.

In OPEN WATER from the coast out to greater depths, v±E communities are followed by E. fil.

In more CLOSED waters, from the coast outwards, d communities are followed by b ± E, and these by c ± E.

Having identified the communities in Danish and neighbouring waters, Petersen has directed his attention to the consideration of the distribution of animals in other areas, and has arrived at the conclusion that very similar communities to those discovered in Denmark occur in far-distant waters, and in Chart I attached to Appendix to Report XXI from the Danish Biological Station he has given a graphic prediction of the distribution of his animal communities in waters outside the Danish area, which he submits as a rough skeletal basis. In the communities he has utilised, however, he has ignored various subdivisions known to him from Danish waters, and the Abra, Venus and deep Venus communities (above) are in consequence grouped together under one main heading of **Venus Communities** with **Spatangidæ.** More recent work, also, has resulted in the suggested addition of two further communities, one, the E. fil., to be included as the next deepest community to the Venus group (6, page 13). Interpreting the chart, then, on the broadest lines, it would indicate that the level bottom in the waters off Plymouth is populated chiefly by Venus communities with, however, some representation of E. fil., as well as a possible influence from the little known Lusitanian group. It would also be fair to expect the Macoma community to be represented on the shore areas of Plymouth Sound, although the chart does not actually indicate this, probably owing to the limitations imposed by the small scale of the drawing.

I may now conveniently proceed to the study of the results of the actual



To face page 167.

working of the bottom-sampler in the Plymouth area, the extent of which is shown on the accompanying Charts.

In the first place, it will be seen that the Plymouth Breakwater practically shuts off the Sound from the more open Channel waters, so that, in accordance with experience in Danish waters, the effects of this enclosure should be reflected in the constitution of the respective animal communities. It is, therefore, of interest to note that the leading Spatangids, *Echinocardium cordatum*, *Spatangus purpureus*, and *Echinocardium flavescens* do not occur characteristically anywhere in the Sound, whereas they are regularly met with in the open Channel—in the case of *Echinocardium cordatum* from the shore outwards to the limits of the area. Again, outside the Breakwater varying degrees of sheltering are exhibited, so that a corresponding variation in community variation should be evident. With regard to the sea-bottom itself, there is the most important factor that the bottom deposits both in the Sound and outside are far from being uniform either in texture or in the distribution of the various grades of texture. Leaving out of account such questions as to what extent differences in bottom soil in themselves control animal distribution, or to what degree such differences are merely the expression of other influences such as tides and currents, there can be no doubt that this variation and "patchiness" of the bottom deposits add very considerably to the difficulties in determining a satisfactory faunistic picture. Variation in soil involves changes in the efficiency of the bottom-sampler, and on such stony ground as may be met with, for instance, on the Looe-Eddystone fishing grounds, the latter instrument is almost useless. "Patchiness" in ground necessitates many more hauls than would be necessary on a uniform bottom to ensure that nothing of importance is being overlooked; a number of instances could be given from the work now under review, where a slight alteration in the position of the ship has resulted in a most striking change, both in the nature of deposit and the proportion of the animals contained in the successive hauls of the bottom-sampler. With regard to the fauna, it is noticeable that a number of species generally occurring together in one particular kind of soil become split up into smaller groups under other bottom conditions. Thus, then, if one accepts the conception of animal communities, one must be prepared in practice to discover, on uneven ground as regards bottom soil, fewer or more groups of possibly quite different kinds of animals, while the typical community formation may only occur in localised areas. It is just this experience which leads me to suggest that clearly defined information as to the general constitution of a community, as well as its leading characteristic species, is necessary in order that the smaller groups due to "non-typical" conditions may be correctly identified.

From the results so far obtained I am of the opinion that at least two distinct main series of level bottom animals exist alongside one another in Plymouth waters, the one expressing itself in several recognisable forms in deposits in which fine grades predominate, and the other being restricted to coarser soil, with its typical form restricted to clean shell-gravel. Adopting the system of soil-grading utilised by Allen (1, page 378), it may be stated that the first series is found where Grades VI, VII, and VIII predominate; and the second where Grades II, III, and IV are of the greatest importance, and consist largely of shell fragments. That the difference between these series is a real one is shown by the fact that each has its own characteristic spatangids and lamellibranchs, which do not occur in the other. For the reason already given above, Table 1 has been drawn up purposely to show fairly fully the species which have proved most useful in the recognition of the two series and of the various smaller groups met with in the general survey of the grounds. The selection of the species has been governed by three factors: their facility in identification, their relative abundance, and their observed distribution.

The choice of specific names raised some difficulty, but it was eventually decided to adhere to the name recorded in the published fauna lists of the Marine Biological Association, where references are given to good descriptions of the animals concerned, and supplementing, when neces sary, from well-known and accessible works. The names utilised will therefore be found in one or other of the following:—

1. Plymouth Marine Invertebrate Fauna.—*Journ. Mar. Biol. Assoc.*, Vol. VII, No. 2, 1904.

2. Polychaeta of Plymouth and the South Devon Coast, including a list of the Archiannelida.—E. J. Allen, *Journ. Mar. Biol. Assoc.*, Vol. X, No. 4, 1915.

3. List of British Marine Mollusca and Branchiopoda.—*Journal of Conchology*, Vol. 10, No. 1, 1901.

4. Gammaridea.—T. R. R. Stebbing, *Das Tierreich. Lief* 21, 1906.

5. Crustacea of Norway.—G. O. Sars.

6. History of British Stalk-eyed Crustacea.—T. Bell.

7. Faune de France—Échinodermes.—R. Kœhler, 1921.

It is a little unfortunate that the specific names adopted are not in complete agreement with those used by Petersen, and in order to avoid confusion, the following important differences should be noted:—

Names used in present work.	Names used by Petersen.
Syndosmya alba (Wood).	*Abra alba.*
Syndosmya prismatica (Montagu)	*Abra prismatica.*
Thyasira flexuosa (Montagu).	*Axinus flexuosus.*
Tellimya ferruginosa (Montagu)	*Montacuta ferruginosa.*
Spisula elliptica (Brown).	*Mactra elliptica.*
Spisula subtruncata (da Costa).	*Mactra subtruncata.*
Gari ferroensis (Chemnitz).	*Psammobia faeroensis.*
Cultellus pellucidus (Pennant).	*Solen pellucidus.*
Ensis ensis (Linnæus).	*Solen ensis.*
Turritella communis (Lamarck.)	*Turritella terebra.*

TABLE 1

Series A.	Species occurring in both classes of soil.	Series B.
Typical animals found in bottom deposits in which grades VI, VII, and VIII predominate.		Typical animals found in bottom deposits in which shelly gravel of grades II, III, and IV predominates.
		Amphioxus lanceolatus
Nucula nitida		*Nucula radiata*
		Glycimeris glycimeris
		Lima loscombi
Thyasira flexuosa		
Montacuta bidentata		*Montacuta substriata*
Tellimya ferruginosa		
*SYNDOSMYA ALBA**		
*SYNDOSMYA PRISMATICA**		
*TELLINA FABULA**		*Tellina crassa*
		Tellina pusilla
Donax vittatus		
Mactra stultorum		
*SPISULA SUBTRUNCATA**	**SPISULA ELLIPTICA*→*	
Lutraria elliptica		*Lutraria oblonga*
	←*Dosinia lupina*	
	Dosinia exoleta→	
Meretrix chione		
VENUS (CHAMELÆA) GALLINA	*Venus (Timoclea) ovata*	*Venus (Clausinella) fasciata*
Tapes pullastra	*Tapes virgineus*→	
		Gouldia minima
Cardium echinatum		*Cardium (Laevicardium) norvegicum*

NOTE.—The arrow-head opposite certain species in middle column indicates the series to which there is a tendency.

* The species in bolder type are *characteristic species* for certain of Petersen's com munities.

TABLE 1—*continued.*

Series A.	Species occurring in both classes of soil.	Series B.
Typical animals found in bottom deposits in which grades VI, VII, and VIII predominate.		Typical animals found in bottom deposits in which shelly gravel of grades II, III, and IV predominates.
*GARI FERROENSIS**		*Gari tellinella*
Mya truncata	*Corbula gibba*	
	←*Solecurtus antiquatus*	*Solecurtus scopula*
	←*Ensis ensis*	*Ensis arcuata*
Cultellus pellucidus		
*TURRITELLA COMMUNIS**		
*ECHINOCARDIUM CORDATUM**		*ECHINOCARDIUM** *FLAVESCENS*
	Echinocyamus pusillus→	
		*SPATANGUS PURPUREUS**
*AMPHIURA FILIFORMIS**		
Cucumaria elongata		
Leptosynapta inhærens		
Labidoplax digitata		
Gonoplax rhomboides		
Alphæus ruber		
Callianassa subterranea		
Diastylis sp.		
Iphinoe trispinosa		
Bathyporeia pelagica		
Bathyporeia guilliamsoniana		
		Polygordius sp.
Sthenelais limicola		
	Nephthys sp.	
	Lumbriconereis sp.	
		Onuphis brittanica
	Glycera sp.	
Goniada maculata		
Owenia fusiformis		
Magelona papillicornis		
	Lanice conchilega	
Cirratulidæ		
Melinna adriatica		
Pectinaria sp.		
Notomastus latericeus		
Scalibregma inflatum		

NOTE.—The arrow-head opposite certain species in middle column indicates the series to which there is a tendency.

* The species in bolder type are *characteristic species* for certain of Petersen's communities.

Some explanation is necessary with regard to the species which are shown in the table as occurring in both kinds of soil. It is naturally to be expected that some overlapping will occur, and the arrow-heads opposite certain species indicate to which series present experience suggests that the species should be referred. A number of animals, however, appear regularly and commonly in both series, e.g. *Corbula gibba*, which may be reasonably regarded as the equivalent of Petersen's attendant species. Such polychaetes as Nephthys, Lumbriconereis, and Glycera present difficulties in specific identification which detract from their value as possible type forms, so that their prevalence on certain stations cannot be made of as much use as could be desired.

With the two series thus set out it is convenient to make a first comparison with Petersen's communities. It is interesting first to notice that the characteristic species shown in bolder type in Table 1 are those of the Echinocardium-filiformis and Venus communities; and second, that nine of the total of twelve are included under Series A. A closer analysis shows that the remaining three species which are included under Series B are characteristic for Petersen's (v), although other (v) species occur under A. It is evident, therefore, that the proper significance of the two series requires to be determined before further comparisons with Petersen's communities can be made. If we compare the animals classified in Table 1, we become aware of the somewhat striking way in which genera present different species in the two series, e.g. Nucula, Montacuta, Tellina, Spisula, Venus, Cardium, and Gari among the lamellibranchs. Petersen (5, page 17), in a discussion on the factors in the formation of communities, makes mention of a similar circumstance noted by him in earlier days on the cruises of the *Hauch*, and writes :—

> "... that closely related species, especially those of the same genus, are scarcely ever found living in one and the same area of a given water; they may meet and fight out their war on a frontier line, but are never found to cover the same area of distribution altogether. *Each has its own region, its own community.** The competition must be greatest between those species which are most closely related."

This appears to me to provide the key to the proper relationship existing between Series A and B. **They are independent associations largely built up of species of genera which are common to both,** and **possess equal potentiality for expressing minor associations under certain circumstances.** Each has its own characteristic species, including a Spatangid and a Venus. Series A is an Echinocardium cordatum—

* The italics are my own.—E. F.

Venus gallina association, EcVg, and Series B a Spatangus purpureus—Venus fasciata association, SpVf. They occur in similar depths of water, but differ in the type of bottom deposit in which they thrive. It will be observed that the symbols EcVg and SpVf have been used here for the first time. While it is admitted that the introduction of new terms makes the reading of papers of this kind more difficult to those unacquainted with previous work, yet such additions seems unavoidable. The following summary of the symbols used herein may therefore prove useful for reference:—

SYMBOLS USED.

Species.	Symbols. As used by Petersen.	As used in present work.
Echinocardium cordatum . .	E	Ec
Spatangus purpureus . . .	—	Sp
Amphiura filiformis . . .	fil	fil
Venus gallina	v	Vg
Venus fasciata	—	Vf
Syndosmya (Abra) alba . .	b	b
Syndosmya (Abra) prismatica . .	—	(b)
Mactra stultorum . . .		*stult*
Macoma baltica . . .	d	d
Astarte sp.	a	a
Turritella communis . . . =Turritella terebra	T	T

Returning now to the consideration of Petersen's (v) it becomes apparent that it is characterised by five species, of which two belong to an Echinocardium cordatum—Venus gallina association, and three to a Spatangus purpureus—Venus fasciata association. This, to my mind, necessitates the discarding of (v), on account of its composite structure, and the substitution of deeper water formations for each of the two Spatangid-Venus associations.

It has been shown above that the three species utilised by Petersen for characterising his E-fil. community are included under Series A. No ground has yet been located, however, where *Amphiura filiformis* and *Turritella communis* occur together characteristically, although fil. has been taken regularly and in numbers at Bigbury, and T. occurs in dense

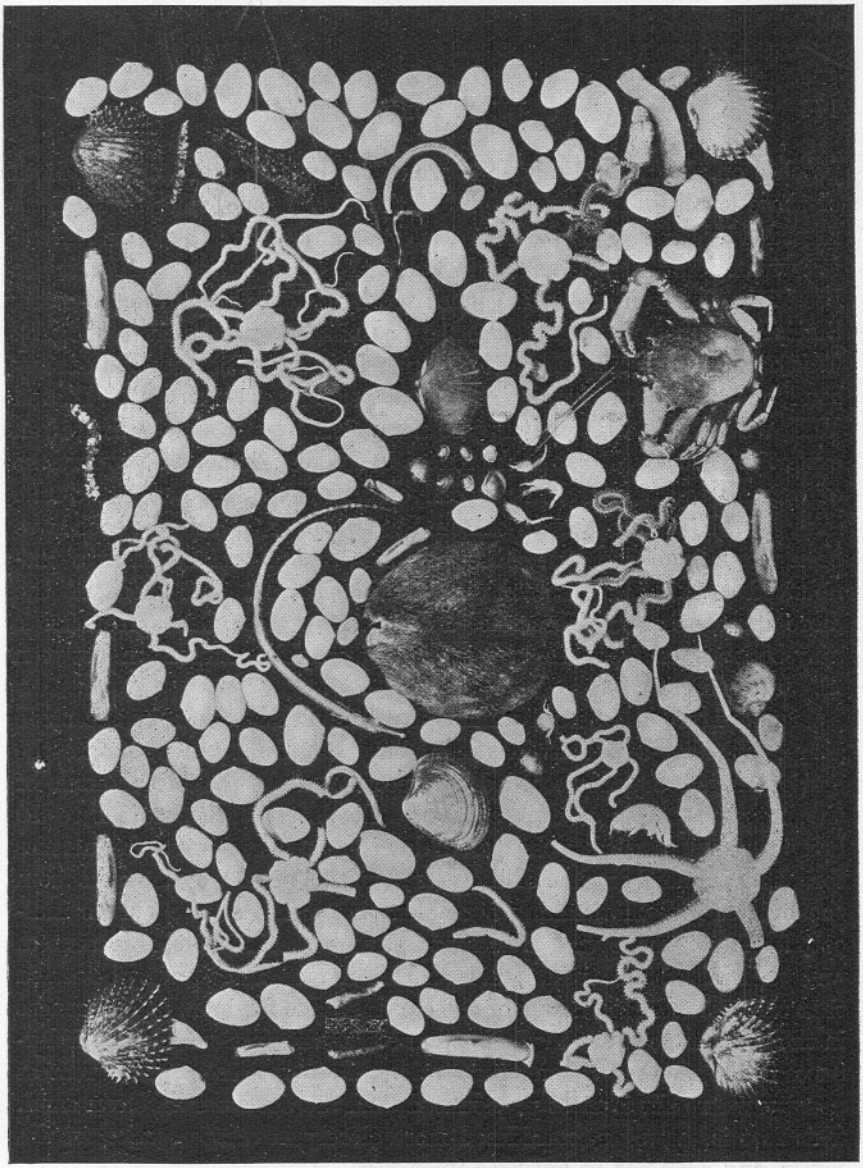


FIG. 1. EcVG COMMUNITY. b+Ec.+fil.

Number of animals per $^1/_{10}$ sq. metre ($^7/_{10}$ natural size).

	No.		No.
Nucula nitida	4	Portunus sp. (juv.)	1
Montacuta bidentata	4	Schizopoda	1
Syndosmya alba	188	Nika edulis	1
Syndosmya prismatica	1	Diastylis sp.	1
Mactra stultorum	1	Ampelisca sp.	1
Venus gallina	1		
Venus ovata	1	Nephthys sp.	1
Cardium echinatum	4	Sthenelais limicola	1
Corbula gibba	1	Owenia fusiformis	1
Cultellus pellucidus	8	Goniada maculata	1
		Lumbriconereis sp.	1
Natica alderi	1	Ammotrypane aulogaster	1
Bullinella cylindracea	1	Pectinaria sp.	3
		Polychaeta, sandy tubes	fragments
Echinocardium cordatum	1		
Amphiura filiformis	1	Nemertinea	1
Ophiura ciliaris	1		
Corystes cassivelaunus	1	Syngnathus sp. (juv.)	1

Station 63. Bigbury Bay { Borough Island, N.E. by E. / Bolt Tail, S.E. ½ S. } October 31st, 1922. Silty sand.

patches on the Rame-Eddystone grounds. It is to be noted that both of these localities lie in the heart of the Venus zone, whereas E. fil. is regarded by Petersen as the next deepest community to the Venus. Dealing with fil. first, it is a striking fact that the one ground on which it has been found in numbers is also inhabited by a dense population of many Series A animals, of which *Syndosmya alba* is the most frequent (see Fig. 1). This occurs in Bigbury Bay off Borough Island in a bottom soil of silty sand, one estimation of which showed 98 per cent of Grades VI, VII, and VIII, with Grade VIII claiming 18 per cent. The ground is limited in extent so that considerable differences in soil and numerical proportions of animals are obtained in successive hauls taken, say, at half-a-mile intervals. Frequent samples of from 1 to 10 dips of the sampler each have been taken from June 9th, 1922, onwards, and the results show a pronounced correlation between the numbers of fil. and those of the more important lamellibranchs present. How close this agreement is may be gathered from the accompanying graphic comparison between fil. and b (Fig. 2).

In the figure the actual numbers of individuals taken in the same sample at thirty-seven stations in Bigbury Bay from June, 1922, to the end of May, 1923, are recorded, irrespective of the number of hauls of the bottom-sampler at each station. The latter varies from 1 to 10 hauls per sample, so that the curves do not represent relative frequencies for either stations or time of the year, but this in no way detracts from the evidence of the striking agreement between the two curves indicated. Thus, whenever b is present in numbers, fil. is well represented, and when b is at a minimum, fil. is also low in numbers. It may be added that the marked irregularity of the curves is due far more to differences in the percentage of silt in the bottom soil at the stations than to differences in the number of hauls per station; both species occur in greatest density where silt is most pronounced, and are absent from clean sand. This fact is, however, considered more closely in a late section of the paper, and need not be enlarged upon here.

We are, therefore, faced by the important fact that here are two species, fil. and b, occurring regularly together in the same area, in corresponding intensity, which are defined as characteristic for different communities. What does this mean? According to Blegvad (2, pages 54 and 62), both species are essentially detritus feeders, so that their frequency in and restriction to a soil at Bigbury in which the finest deposits are well represented, would not be inconsistent with this mode of feeding. On the other hand, Petersen says (4, page 26):—

> "At places where the Amphiuræ live in such quantities that they form a dense net over the sea-bottom . . . but little of the tiny

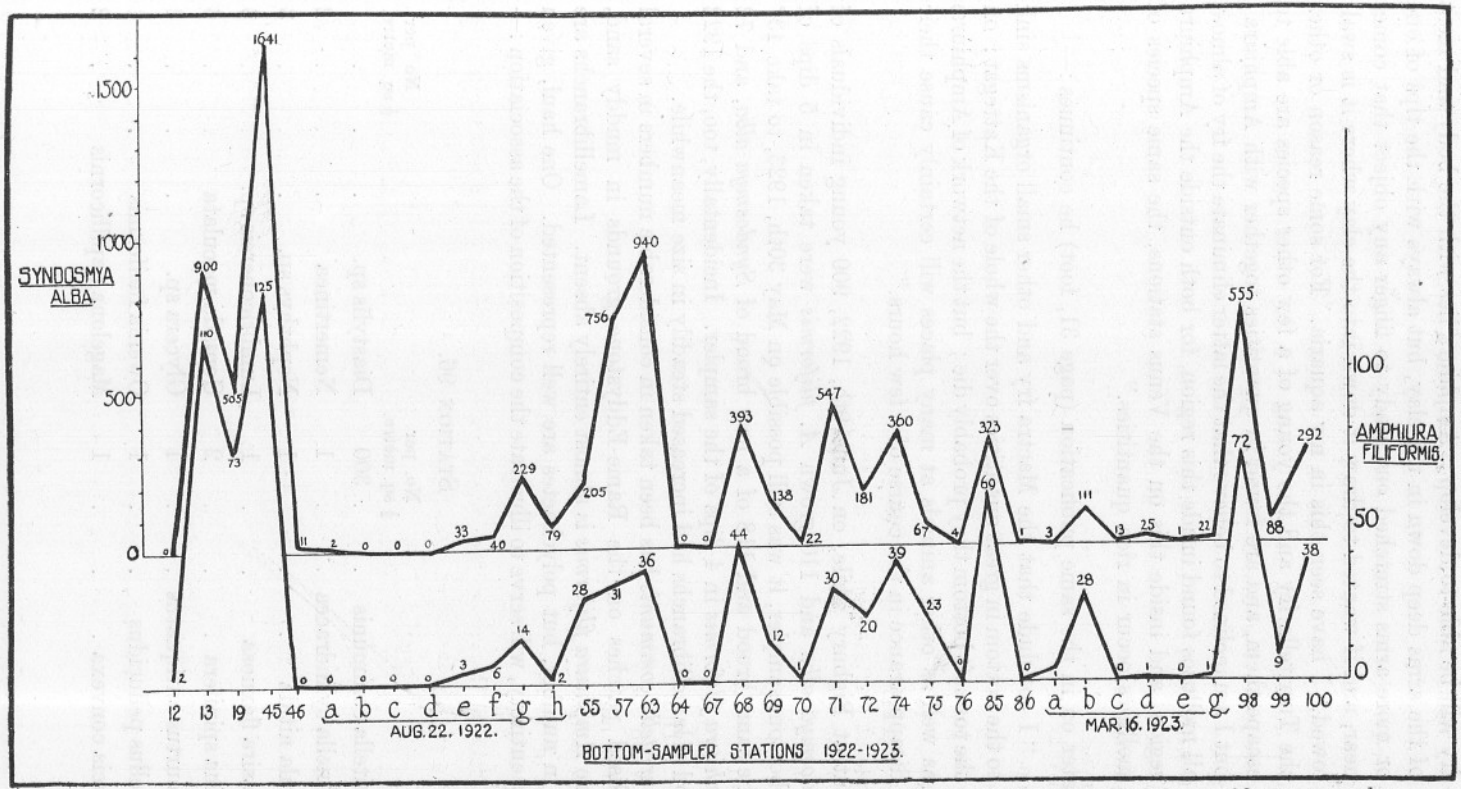


FIG. 2.—Number of individuals of *Syndosmya alba* and *Amphiura filiformis* in the same sample of from 1 to 10 hauls of the $\frac{1}{10}$m² bottom sampler, at each of 37 stations in Bigbury Bay, from June 9th, 1922, to May 30th, 1923.

fry will be able to develop ; Amphiura lies with the body and most of the arms deep down in the clay, but always with the tips of one or more arms stretched out ready to finger any object that comes near, and if wanted to draw it down into the clay where it is swallowed. I have seen this in my aquaria. For some reason or other the Turritella fry and the young of a few other species are able to escape them, and are found in quantities together with Amphiura ; but I am inclined to believe that the latter eliminate the fry of almost all molluscs found inside this region, for both outside the Amphiura region, and inside this on the Venus stations, the same species of molluscs occur in rich quantities."

Later on in the same publication (page 31, foot) he continues :—

"I conclude that the Mactra fry and other small organisms sink to the bottom in great quantities over the whole of the Kattegat ; on the too soft bottom they probably die ; but the network of Amphiuræ as well as other animals at many places will certainly cause their disappearance in the course of a few hours."

But at Bigbury while, on June 9th, 1922, 900 young individuals of *Syndosmya alba* and 110 grown *A. filiformis* were taken in 5 dips of the bottom-sampler, it was still possible on May 30th, 1923, to take 437 of the same brood and 118 of a new brood of *Syndosmya alba*, and 72 *Amphiura filiformis* in 4 dips of the sampler. Incidentally, too, the 1922 brood of lamellibranchs had increased steadily in size meanwhile.

Turritella communis has been taken in considerable numbers in several localised patches on the Rame-Eddystone grounds in muddy sand, where *Amphiura filiformis* is almost entirely absent. Lamellibranchs are few in number, but polychaetes are well represented. One haul, given in its entirety, will serve to illustrate the composition of the association :—

STATION 96.

	No. per ½ sq. metre.		No. per ½ sq. metre.
Turritella communis	300	Diastylis sp.	1
Bullinella cylindracea	1	Nemertinea	2
Nucula nitida	1	Nephthys sp.	3
Thyasira flexuosa	1	Lumbriconereis sp.	3
Lucina spinifera	2	Goniada maculata	6
Solecurtus antiquatus	1	Glycera sp.	2
Cultellus pellucidus	1	Owenia fusiformis	1
Thracia convexa	1	Magelona papillicornis	2

	No. per ½ sq. metre.		No. per ½ sq. metre.
Cucumaria elongata	4	Notomastus latericeus	fragments
Cucumaria sp.	1	Melinna adriatica	1
Amphiura filiformis	1	Ammotrypane aulogaster	1
Gonoplax rhomboides	1	Aricia sp.	1
Alphæus ruber	1	Cirratulidæ	1
Ampelisca sp.	7	Terebellidæ.	3

In a later section of this paper, a subdivision of the EcVg community designated as EcVg *mud* will be described, and without entering into the question of its composition, it may here be pointed out that this haul 96 includes its essential animals. Thus, as with *A. filiformis*, *T. communis* occurs in association with Venus animals (see Fig. 3). It is also of interest to note that large numbers of the shells of *T. communis* are frequently met with on the Rame-Eddystone grounds at Venus stations. In some cases, the shells are quite empty, but in others they may be occupied by either *Anapagurus lævis* and Eupagurus sp. juv., or *Phascolion strombi*, and form the most important item in the fauna. Frequently, also, individuals of Sagartia sp. are to be found attached to the shells.

From the results of present work then, matters must rest in the position that although the two leading species of E. fil. both occur in the Plymouth district, they are not in association, but appear to live separately in localised areas, which are not only surrounded by Venus formations, but are themselves populated by Venus animals.

Of the ten species selected by Petersen for characterising his Venus associations, we have already seen that seven are included under our Series A or EcVg association, and three under Series B or SpVf association :—

Series A (EcVg)	Series B (SpVf)
Echinocardium cordatum.	*Spatangus purpureus.*
Venus gallina.	*Echinocardium flavescens.*
Tellina fabula.	*Mactra elliptica.*
Spisula subtruncata.	
Syndosmya alba.	
Syndosmya prismatica.	
Gari ferroensis.	

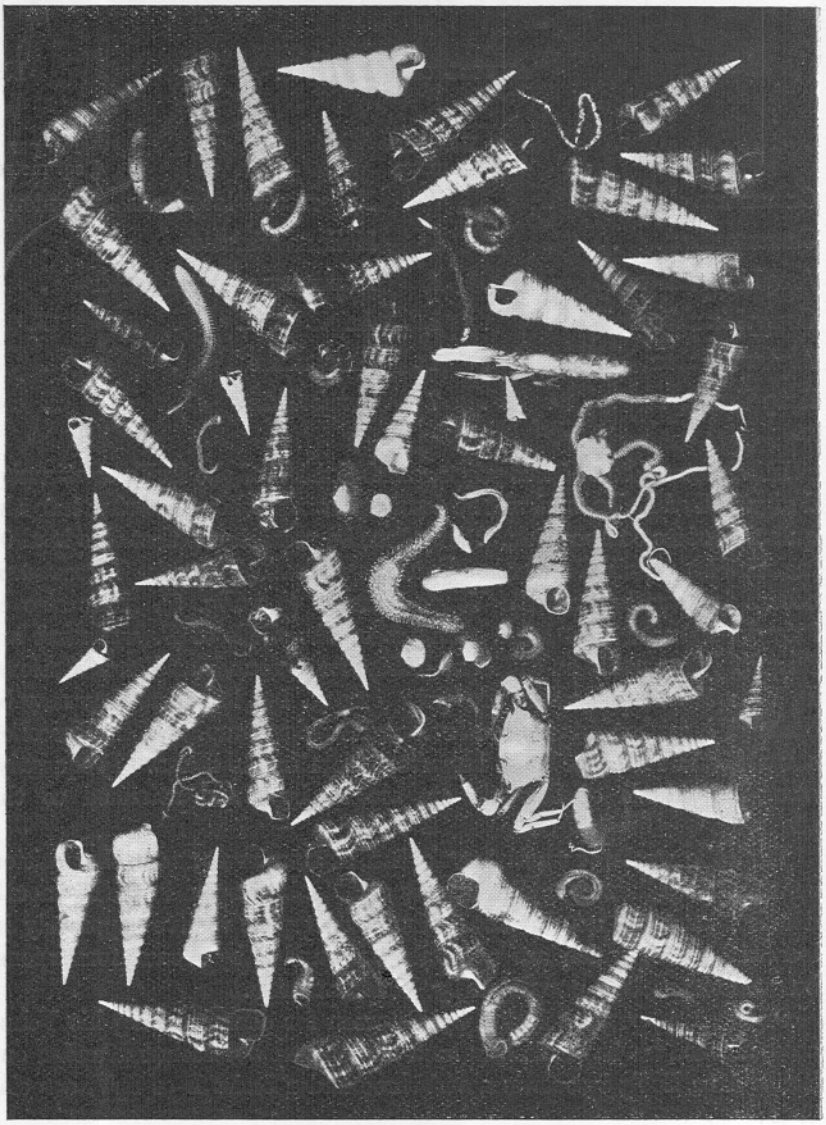


FIG. 3. VG + TURRITELLA COMMUNIS.

Number of animals per $^{1}/_{10}$ sq. metre ($^{6}/_{10}$ natural size).

	No.		No.
Nucula nitida	1	Diastylis sp.	1
Lucina spinifera	1	Ampelisca sp.	1
Thyasira flexuosa	1	Melinna adriatica	1
Solecurtus antiquatus	1	Notomastus latericeus	fragments
Cultellus pellucidus	1	Nephthys sp.	1
Thracia convexa	1	Glycera sp.	1
		Goniada maculata	1
Bullinella cylindracea	1	Magelona papillicornis	1
Turritella communis	60	Owenia fusiformis	1
		Ammotrypane aulogaster	1
Cucumaria elongata	1	Cirratulidæ	1
Amphiura filiformis	1	Lumbriconereis sp.	1
		Aricia sp.	fragments
		Terebellidæ	1
Gonoplax rhomboides	1		
Alphæus ruber	1	Nemertinea	1

Station 96. Rame Head, N.E. by E. $\frac{1}{2}$ E. $1\frac{1}{2}$ miles. May 9th, 1923. Muddy coarse sand with some shell fragments.

Of the seven species included under EcVg, *Tellina fabula*, *Spisula subtruncata*, and *Gari ferroensis* have not been taken in sufficient numbers to warrant their use as leading species ; but the fact remains that when they *are* present, they occur under EcVg conditions. *E. cordatum* occurs quite generally on the sandy grounds outside the Breakwater from the shore outwards to the limits of the area, but not within Plymouth Sound. *Venus gallina* is likely to be met with both inside and outside the Breakwater on any of the EcVg stations, although it has never been taken in numbers comparable to those experienced in Danish waters. Its general distribution, however, is significant in the consideration of the Venus communities, for its presence in Series A and absence from B affords evidence of the distinction between the series. *Syndosmya alba* and *S. prismatica* are both well represented in outside waters, and the former also within the Sound, and there is a good indication that *S. prismatica* is more typical of deeper water, thereby confirming the reasonableness of its use by Petersen for the characterisation of a deeper Venus formation.

Owing to the varied nature of the bottom in Plymouth waters, and to the corresponding patchiness in fauna resulting from it, it will be realised that the fullest expression of EcVg will not be generally distributed. Examination of the results suggests, however, that silty sand is most favourable for the most typical expression of EcVg, and that a change to either fine clean sand, or in the opposite direction to black mud, produces a more specialised association. Remembering the "depth" distinction between the two species of Syndosmya, also, we may therefore refer to four distinct sub-groupings of the EcVg series :—

SUB-GROUPS OF SERIES A (EcVg).

Sub-group 1. Clean sand.	Sub-group 2. Silty sand shallower.	Sub-group 3. Silty sand deeper.	Sub-group 4. Black mud.
	Syndosmya alba	Syndosmya prismatica	(Syndosmya alba)
Mactra stultorum Venus gallina Ensis ensis	Mactra subtruncata Venus gallina Cultellus pellucidus Nucula nitida Cardium echinatum Montacuta bidentata		(Cultellus pellucidus) (Thyasira flexuosa)
(Meretrix chione) (Donax vittatus) (Lutraria elliptica juv.)			

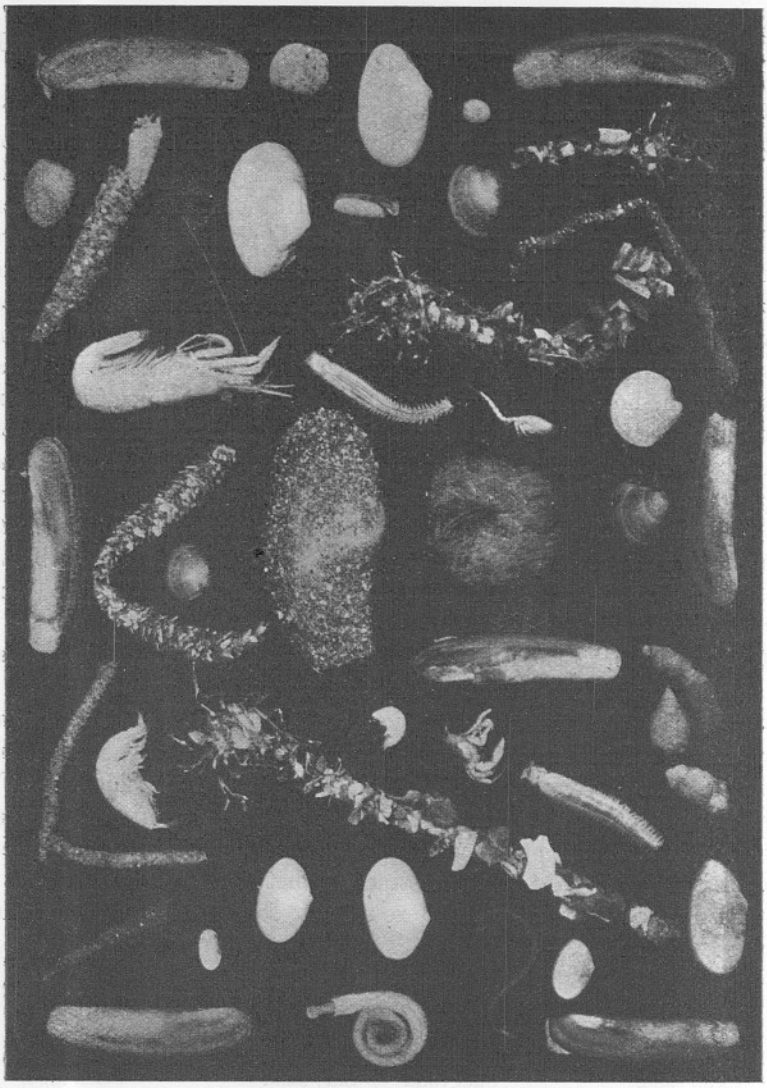


FIG. 4. EcVG COMMUNITY. b dominant over (b).

Number of animals per $^{1}/_{10}$ sq. meter ($^{11}/_{10}$ natural size).

	No.		No.
Nucula nitida	4	Nika edulis	1
Tellimya ferruginosa	1	Diastylis sp.	1
Syndosmya alba	5	Ampelisca sp.	1
Syndosmya prismatica	1		
Dosinia lupina	1		
Cultellus pellucidus	7	Nephthys sp.	2
Lyonsia norvegica	1	Sthenelais limicola	1
		Owenia fusiformis	1
Bullinella cylindracea	1	Goniada maculata	1
Natica alderi	1	Pectinaria sp.	1
		Lanice conchilega, tubes	frequent
Echinocardium cordatum	1	Polychaeta, tubes	frequent
Echinocyamus pusillus	1		
Anapagurus lævis	1	Nemertinea	1

Station 104. Borough Island E., Revelstoke Point N.E. by N. June 12th, 1923. Silty sand with some flaky shell fragments.

SUB-GROUPS OF SERIES A (EcVg)—*continued.*

Sub-group 1. Clean sand.	Sub-group 2. Silty sand shallower.	Sub-group 3. Silty sand deeper.	Sub-group 4. Black mud.
	Syndosmya alba	Syndosmya prismatica	
Bathyporeia sp. Iphinoe trispinosa	Diastylis sp.		Diastylis sp. Gonoplax rhomboides Alphæus ruber Callianassa subterranea juv.)
Echinocardium cordatum	E. cordatum		
			Cucumaria elongata
			Melinna adriatica Notomastus latericeus Cirratulidæ
Nephthys sp. Owenia fusiformis	Nephthys sp. Owenia fusiformis Pectinaria sp. Goniada maculata Glycera sp. Sthenelais limicola		Nephthys sp. Goniada maculata Glycera sp. Sthenelais sp.
Polychæta with sandy tubes	Polychaeta with sandy tubes		

The importance of the nature of the bottom deposits in determining the fauna is thoroughly well illustrated by the results of a series of hauls taken in Bigbury Bay, passing from the clean sand inshore across the silty b fil. patch to relatively clean shell gravel. On August 22nd, 1922, nine separate single dips of the sampler were taken at short distances apart (see Chart facing page 167) and the numbers of certain species are given below which show quite distinctly the passage from animals of Sub-group 1 (above) to those of Sub-group 2 :—

August 22nd, 1922.	a	b	c	d	e	f	g	h	i
No. of hauls of $\frac{1}{10}$m^2 sample	1	1	1	1	1	1	1	1	1
Nature of soil.	Clean sand.	Clean sand.	Clean sand.	Clean sand.	Silty sand.	Silty sand.	Silty sand.	Silty sand.	Shelly gravel.
Mactra stultorum	—	—	1	—	—	—	—	—	—
Ensis ensis (juv.)	2	8	1	—	—	—	—	—	—
Lutraria elliptica	—	—	—	1	1	2	—	—	—
Syndosmya prismatica	—	2	1	—	2	—	—	—	—
Syndosmya alba	2	—	—	—	33	40	229	79	—
Cultellus pellucidus	1	3	—	2	5	6	23	18	—
Cardium echinatum	—	—	1	1	2	1	4	3	—
Venus gallina	—	—	—	1	—	—	—	—	—
Nucula nitida	—	—	—	2	6	1	1	—	—
Montacuta bidentata	—	—	—	—	1	4	14	—	—

August 22nd, 1922.	a	b	c	d	e	f	g	h	i
No. of hauls of $\frac{1}{10}$m² sample	1	1	1	1	1	1	1	1	1
Nature of soil.	Clean sand.	Clean sand.	Clean sand.	Clean sand.	Silty sand.	Silty sand.	Silty sand.	Silty sand.	Shelly gravel.
Diplodonta rotundata	—	—	—	—	1	—	—	—	—
Thyasira flexuosa	—	—	—	—	—	—	2	—	—
Corbula gibba	—	—	—	—	4	—	—	1	—
Spisula subtruncata	—	—	—	—	—	—	1	—	—
Gari tellinella	—	—	—	—	—	—	—	—	1
Echinocardium cordatum (juv.)	1	—	1	—	—	1	3	—	—
Amphiura filiformis	—	—	—	—	3	6	14	2	—
Bathyporeia pelagica	1	1	—	1	—	—	—	—	—

As a second illustration, two hauls of the sampler taken on the same day, February 14th, 1923, at stations separated slightly over one mile may be compared :—

	No. of Dips of Sampler	Station 85 5	Station 86 5
[Allen's grades]	Nature of Soil. Grades VI, VII and VIII	98·0%	99·0%
	Grade VIII	18%	0·2%
Mollusca.			
	Mactra stultorum	—	2
	Ensis ensis (juv.)	—	1
	Syndosmya alba	323	1
	Syndosmya prismatica	3	1
	Spisula subtruncata	1	—
	Venus gallina	—	2
	Venus ovata	—	1
	Cultellus pellucidus	24	—
	Nucula nitida	49	1
	Cardium echinatum	10	—
	Montacuta bidentata	22	—
	Thyasira flexuosa	10	—
	Diplodonta rotundata	1	—
	Corbula gibba	—	1
	Bullinella cylindracea	1	—
	Nassa reticulata	1	—
Echinoderma.			
	Echinocardium cordatum	1	—
	Amphiura filiformis	69	—
	Ophiura ciliaris	10	—

	Station 85	Station 86
No. of Dips of Sampler	5	5
Nature of Soil.		
Grades VI, VII and VII	38·0%	99·0%
Grade VII.	18%	0·2%
Crustacea.		
Decapoda	1	—
Monoculodes carinatus	2	1
Bathyporeia sp.	—	3
Diastylis	3	1
Iphinoe trispinosa	—	4
Polychæta.		
Nephthys sp.	2	6
Owenia fusiformis	12	—
Pectinaria sp.	1	—
Goniada maculata	2	—
Sthenelais limicola	4	1
Phyllodocidæ	1	—
Polynoidæ	1	—
Lumbriconereis sp.	1	—
Sandy tubes	—	sev.

Sub-group 1, typical of clean sand, shows a marked reduction in the number of commonly occurring lamellibranchs; but those which persist are distinctive, *Mactra stultorum* being probably the one most generally met with. *Venus gallina* here assumes relative importance, although possibly more on account of the scarcity of other species than on its own increased intensity. *Ensis ensis* frequently occurs in place of *Cultellus pellucidus*, which is so frequent in Sub-groups 2 and 3. Two species of Bathyporeia and the Cumacean *Iphinoe trispinosa* have only as yet been taken regularly and in numbers in clean sand, and would therefore appear to be of use in defining the sub-group. Among the polychaetes, individuals of Nephthys sp. are always taken in numbers, and sandy-tube dwellers are prevalent.

In Sub-group 4, typical of black mud (see Fig. 5), the reduction in lamellibranchs is still more apparent, while *Echinocardium cordatum* is for all practical purposes absent. Polychaetes are very abundant, however, and the most obvious feature of the hauls is the presence of large numbers of the ampharetid *Melinna adriatica* and its muddy tubes. The capitellid *Notomastus latericeus* is also common, and Cirratulids, Glycera, Goniada, Nephthys, Scalibregma, Magelona, and Lumbriconereis are well repre-

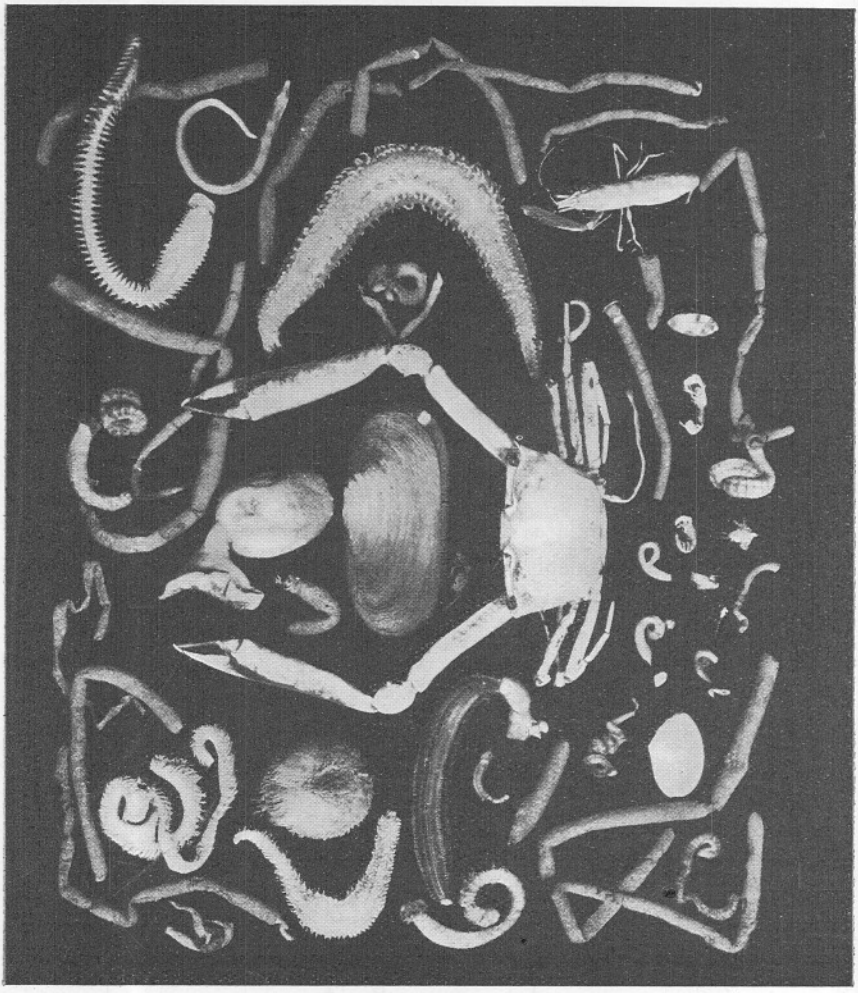


FIG. 5. EcVg COMMUNITY. EcVg MUD.

Number of animals per $^{1}/_{10}$ sq. metre ($^{8}/_{10}$ natural size).

	No.		No.
Syndosmya alba	1	Melinna adriatica	frequent
Solecurtus antiquatus	1	Notomastus latericeus	frequent
Corbula gibba	1	Nephthys sp.	2
		Glycera sp.	1
Echinocardium cordatum	1	Magelona papillicornis	1
Cucumaria elongata	2	Aricia sp.	1
Gonoplax rhomboides	1	Nemertinea	1
Alphæus ruber	1		
Callianassa subterranea (juv.)	2	Sagartia sp.	1
Corystes cassevelaunus (juv.)	1		
Porcellana longicornis (juv.)	1	Clupea sp., post-larva	1
Diastylis sp.	1	Pleuronectes limanda, post-larva	1

Station 5. Rame Head E. $\frac{1}{4}$ N. $1\frac{3}{4}$ miles. May 31st, 1922. Black mud.

sented. The chief echinoderm is *Cucumaria elongata*, which is of regular occurrence, while Leptosynapta and Labidoplax are not uncommon. The three decapods, *Gonoplax rhomboides*, *Alphœus ruber*, and *Callianassa subterranea*, are generally taken, thereby adding to the distinctive character of this sub-group. This mud formation is obviously different from the others, although it is still composed of EcVg animals. It provides an example of a community expression in which the defined characteristic species of the main community are not typically represented, and demonstrates the need for a full description of the general composition of all defined animal communities, in order that such specialised expressions may be recognised.

The naming of these four sub-groups requires some consideration.* The more typical, Nos. 2 and 3, are to be regarded merely as depth formations of the full EcVg expression. It is to be anticipated that at intermediate depths, *Syndosmya alba* and *S. prismatica* may occur in equal and not necessarily large numbers, when the formation may be termed Vg+Ec as the equivalent of Petersen's v+E. In shallower or sheltered waters, when Sub-group 2 is exhibited, the formation may rightly be termed b+Ec ; while in deeper waters (b) seems an appropriate abbreviation, for it indicates the importance of *Syndosmya* (*Abra*) *prismatica* (b), but at the same time avoids any possible confusion with the composite (v) of Petersen. Sub-group 1 merits a distinctive term, for it is a recognisable formation both in Bigbury Bay and Whitsand Bay, and Vg *stult.*+Ec may be utilised, although it is clearly a reduced form of Vg+Ec. The naming of Sub-group 4 raises a peculiar difficulty, for Echinocardium and lamellibranchs generally are not sufficiently regular in occurrence to be used for characterisation. EcVg *mud* may, however, suffice for distinctive abbreviation.

With regard to the SpVf series (see Fig. 6) it must be admitted that no definite sub-community groupings equivalent to those of EcVg have as yet been attempted. The grounds are much more localised, and differ considerably in the number of species which they contain. The distribution of the typical community species is evidently influenced by the degree of coarseness of gravel, the relative amount of shell fragments, and the amount of silt. For instance, Amphioxus and Polygordius may be associated in being restricted to a clean soil almost entirely made up of broken shell fragments of medium and fine grades, whereas Venus fasciata is not so restricted. The important fact remains that the fullest community expression of SpVf occurs only where the soil is relatively clean, and consists of gravels with a big proportion of shell, whereas that of EcVg is restricted to deposits of silty sand.

* The composition of Petersen's communities is shown on page 165 of this paper; and on page 172 a summary of abbreviations used herein will be found.

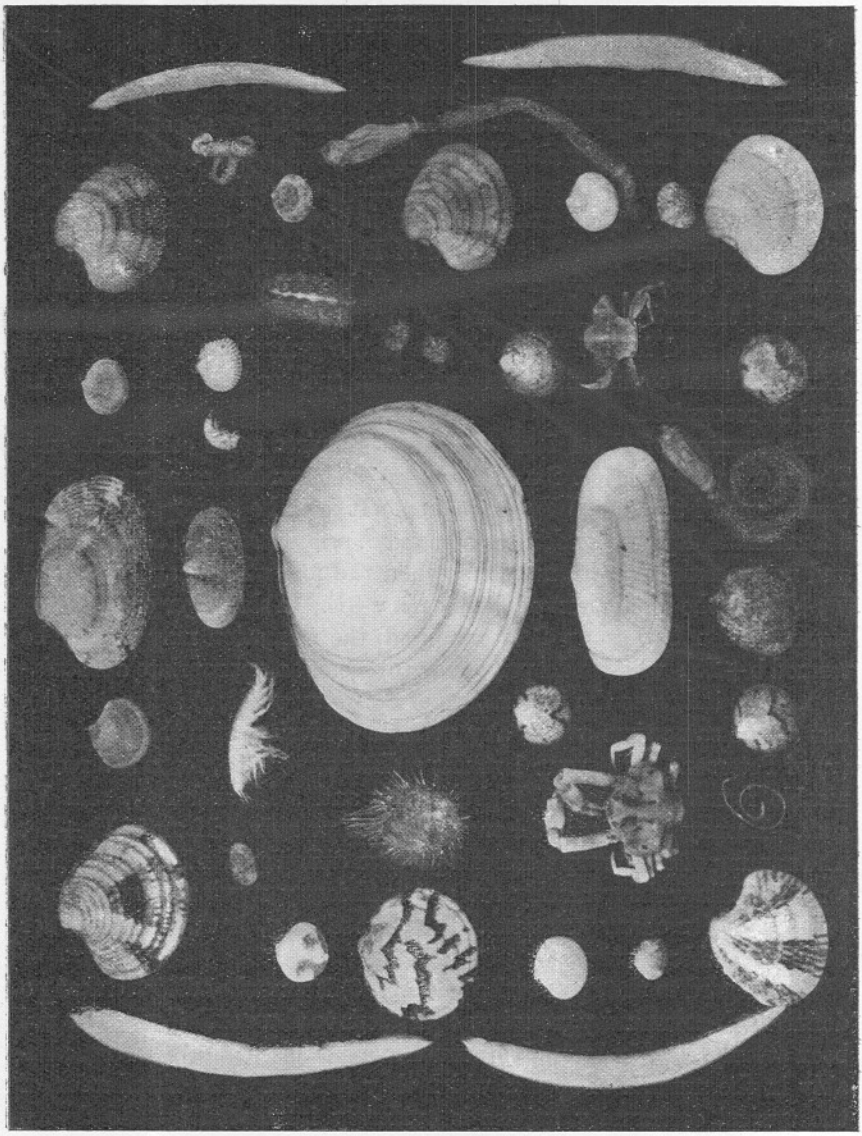


FIG. 6. SpVF COMMUNITY.

Number of animals per $^{1}/_{10}$ sq. metre ($^{11}/_{10}$ natural size).

	No.		No.
Glycimeris glycimeris	5	Echinocyamus pusillus	2
Tellina crassa	1		
Tellina pusilla	1	Portunus pusillus	1
Venus fasciata	5	Ebalia tuberosa	1
Venus ovata	2	Ampelisca typica	1
Tapes virgineus	1	Maera sp.	1
Gouldia minima	6	Polygordius sp.	fragments
Cardium nodosum	1	Glycera sp.	2
Cardium norvegicum	1	Polynoinæ	1
Gari tellinella	1	Lumbriconereis sp.	1
Echinocardium flavescens (juv.)	1	Amphioxus lanceolatus	4

Station 81. Eddystone S.S.E. ½ E. ½ mile. January 25th, 1923. Clean shell gravel.

Owing, again, to the general irregularity in bottom deposits over the area, a large part of the whole must be regarded as unsuitable for the full expression of either EcVg or SpVf. In some cases the conditions will permit of some of the species from both communities living together, and "mixed" hauls will be the result. It is also possible that on the rough and stony grounds, where good sampling with the bottom-sampler is practically impossible, there may be another series of animals. In this connection it is worth noting that on two occasions only *Nucula nucleus* has been taken in fair numbers (Stations 6 and 106), and both from deposits of muddy coarse materials. In haul 6, *Astarte sulcata* also occurred—the solitary record of this species.

In Plymouth Sound both EcVg and SpVf are well represented, although, as already stated, without their leading Spatangids. SpVf occurs in its most typical form on Queen's Ground, with a dense growth of young *Spisula elliptica* outnumbering everything else during the summer of 1922. The association (with the exception of the Spisula growth) bears a close resemblance to that of the Eddystone shell-gravel (cf. Stations 23, 35, etc., with Stations 20 and 81, etc.), with certain exceptions of the relative frequency of a few species in the two localities. On July 24th, 1922, a dense growth of young *Mytilus edulis* was located on the shallower more inshore part of this ground. This provides an interesting instance of the invasion, possibly only temporarily, of a Venus community by an Epifaunal species of the inshore Macoma community.

SpVf is also represented on two other grounds, though in reduced form—off Bovisand Pier, where *Mactra elliptica* (juv.) also occurred in numbers in 1922; and off Melampus Buoy, but here, to some extent, mixed with a sandy EcVg fauna.

The bottom of the greater part of the Sound is covered with either black mud, or sand, or a mixture of the two in varying proportions, and it is populated essentially by EcVg animals. The sub-community associations b and EcVg mud are undoubtedly the most pronounced, the hauls of the bottom-sampler showing varying degrees of mixing corresponding to the changes in proportion of mud to sand. In Jennycliff Bay, where the deposits are almost wholly black mud, Melinna and other polychaetes occur in abundance, and *Syndosmya alba* is well represented. There is in addition a rich growth of *Thyasira flexuosa*. As one leaves the mud and enters muddy sand, such as may occur in moving to the neighbourhood of the anchorage buoys, b becomes more pronounced, until, in sandy mud, it is dominant over the EcVg mud species, and the fauna may be compared quite fairly with that of the outside b+Ec stations, with, of course, the exception of Ec.

Two other mud grounds are worthy of mention. In the enclosed Millbay Docks, in addition to the typical mud forms, tiny cirratulids

(Heterocirrus (?) sp.) were in enormous abundance on the occasion of a sampling on July 10th, 1922. Between Batten Breakwater and the Mallard Buoy, *Tapes pullastra* and *Mya truncata* occur. These two species are reminiscent of Petersen's Macoma community d, although the station is mainly EcVg. Other d animals, e.g. *Arenicola marina*, *Mytilus edulis* live on the shores, and the characteristic species *Macoma baltica* has been recorded from the river off Saltash, which is sufficient evidence of the presence of this complex community in the district.

Petersen's prediction for the Plymouth area may now be reviewed in light of the foregoing account. Without doubt, the grounds are populated chiefly by Venus communities with Spatangidæ, but by TWO VENUS COMMUNITIES, each with a characteristic Venus and a characteristic spatangid, and of equal potentiality for expressing sub-associations. Several of the sub-communities of Petersen's v are recognisable in the district, but (v) cannot be accepted as it is made up of species of both main communities. There is, however, a distinct deeper sub-association of one of the communities which is comparable to (v), and it is suggested that there may also be a deeper sub-association of the other. The characteristic species of Petersen's E. fil. are both represented, but never associated, and they are found separately with Venus animals.

The composition of the two Plymouth Venus communities may be set out as under :—

VENUS COMMUNITIES WITH SPATANGIDÆ.

A. In bottom deposits of fine grades.—*Echinocardium cordatum—Venus gallina community* EcVg.*

A1. In clean sand . . Vg stult ± Ec.

A2. In silty sand . . Vg ± Ec.

A2α. In shallower and sheltered waters b ± Ec.

A2β. In deeper waters . . . (b).

A3. In black mud . . EcVg mud.

B. In bottom deposits of shelly gravel.—*Spatangus purpureus—Venus fasciata community* SpVf.

N.B.—Fil. and T. may occur separately with sub-associations of A.

In the photographs which accompany the text the number of animals per one haul of the $\frac{1}{10}$ sq. metre bottom-sampler, calculated from the results of the hauls at certain stations, is shown. In the case of many species the actual density is considerably less than 1 per $\frac{1}{10}$ sq. metre,

* See footnote to page 185.

but one individual has been included in the photograph to indicate that the species may occur. It should also be noted that in the preparation of the photographs no attempt has been made to represent the actual size of the piece of ground ($\frac{1}{10}$ sq. metre), and the animals have been arranged to exhibit clearly the general composition of the particular community formation.

During the summer of the year 1921, Mr. J. R. Baker carried out quantitative estimations of the animals found in samples of black mud, fine sand, and shell gravel, taken from certain grounds in the Plymouth district. His samples were collected with an ordinary conical dredge provided with a canvas bag, and either ten, twenty, or thirty litres of bottom deposit, according to the amount brought up, were passed through sieves similar in mesh to those utilised by Petersen. His results, when tabulated on a uniform basic sample of twenty litres, are interesting for comparison with those obtained with Petersen's bottom-sampler and recorded above, with regard both to the community formations and the working efficiency of the two collecting instruments. In Table 2 (page 190) I have arranged a number of selected species in a manner conveniently to show at a glance their frequency of occurrence in the three types of deposit.

It is to be noticed that my SpVf species are confined to the shell gravel, and my EcVg species shared by the fine sand and mud, with *Venus fasciata* and *Venus gallina* regularly occurring. In the fine sand EcVg *stult.* species are well represented (although *Mactra stultorum* itself does not appear). This is to be expected, for three of the five samples were taken from Whitsand Bay and Bigbury Bay. The two remaining samples were collected from the offshore Eddystone Grounds, and include *Syndosmya prismatica*, and thus afford confirmation for the existence of my (b) :—

FINE SAND SAMPLES.

Species.	WHITSAND BAY. No. of samples in which present	BIGBURY BAY. No. of samples in which present	EDDYSTONE W. ca 6 miles. No. of samples in which present
Donax vittatus . . .	1	—	—
Meretrix chione . . .	1	—	—
Ensis ensis	1	1	—
Venus gallina . . .	2	1	1
Cultellus pellucidus . .	—	1	2
Syndosmya prismatica .	—	—	1
Echinocardium cordatum .	1	1	1
Iphinoe trispinosa . .	2	1	—
Bathyporeia sp. . . .	1	—	—

TABLE 2.

MR. BAKER'S CONICAL DREDGE SAMPLES. (SUMMER, 1921.) PLYMOUTH.

Species.	Number of samples in which present		
	Shell gravel. Total Samples. 4	Fine sand. Total Samples. 5	Mud. Total Samples. 4
Nucula sp.	2	—	—
Tellina pusilla	1	—	—
Venus fasciata	3	—	—
Gouldia minima	1	—	—
Gari tellinella	3	—	—
Echinocyamus pusillus	3	—	—
Amphioxus lanceolatus	2	—	—
Donax vittatus	—	1	—
Syndosmya prismatica	—	1	—
Meretrix chione	—	1	—
Ensis ensis	—	2	—
Echinocardium cordatum	—	3	—
Amphiura filiformis	—	1	—
Iphinoe trispinosa	—	3	—
Bathyporeia sp.	—	1	—
Owenia fusiformis	—	1	—
Lanice conchilega	—	2	—
Nucula nitida	—	—	2
Thyasira flexuosa	—	—	4
Syndosmya alba	—	—	3
Melinna adriatica	—	—	4
Goniada maculata	—	—	3
Magelona papillicornis	—	—	2
Cirratulus cirratus	—	—	1
Venus gallina	—	4	3
Cultellus pellucidus	—	3	3
Dosinia lupina	2	2	1
Corbula gibba	1	1	1
Nephthys sp.	1	5	2
Glycera sp.	3	2	2
Lumbriconereis sp.	1	1	4

The samples of black mud were obtained exclusively from Plymouth Sound, and compare most favourably with the bottom-sampler hauls in the same localities, the leading EcVg mud polychaetes and *Thyasira flexuosa* being well represented :—

BLACK MUD SAMPLES.

Species.	OFF MALLARD BUOY. No. of samples in which present	RUM BAY No. of samples in which present	JENNYCLIFFE BAY. No. of samples in which present	Average No. of specimens per 1 sample of 20 litres.
Thyasira flexuosa .	2	1	1	9
Syndosmya alba .	1	1	1	5
Venus gallina . .	2	1	—	4
Cultellus pellucidus .	2	1	—	3
Melinna adriatica .	2	1	1	114
Goniada maculata .	1	1	1	11
Lumbriconereis sp. .	2	1	1	14
Magelona papillicornis .	1	1	—	2

It is a little difficult to know how to compare the working efficiency of the conical dredge as used by Mr. Baker with that of the bottom-sampler, for the instruments work on fundamentally different principles. It cannot be denied, however, after the examination of the results of the comparatively few hauls made during the summer of 1921 (see Valuation Lists, p. 221), that the conical dredge was able not only to capture the majority of the more important community species on the grounds investigated, but also to indicate in some degree the relative frequency of certain forms. The great disadvantage of the necessity for towing, whereby exactness in determination of position and of area covered is most seriously reduced, can never be overlooked, especially when working in localities where slight changes in position are of vital importance ; but in spite of this, it is evident that much good work may be accomplished with this instrument. It may be of interest to include here the results of an experiment conducted at Bigbury Bay on May 30th, 1923, when one haul of the conical dredge of about two minutes' duration was taken as nearly as possible in the same place as four dips of the bottom-sampler. The ground chosen was inhabited by a flourishing growth of b fil., with a good variety in animal life in a soft silty soil at a depth of 15 fathoms. The amount of deposit brought up by the dredge had a volume of two and half times that of the four bottom-sampler hauls put together, or, in other words, one dredge haul was equal in

volume to ten of the bottom samples. The numbers of the various animals captured were as follows :—

	Conical Dredge.		Bottom Sampler.
	No. per 1 haul.	No. per 2/5 haul. (calculated).	No. per 4 dips.
Nucula nitida	91	36·4	35
Thyasira flexuosa	14	5·6	17
Montacuta bidentata	35	14	22
Syndosmya alba	1130	452	555
Mactra stultorum	14	5·6	4
Cardium echinatum	42	16·8	13
Cultellus pellucidus	29	11·6	14
Gari costulata	6	2·4	1
Tellimya ferruginosa	—	—	4
Syndosmya prismatica	5	2	—
Spisula subtruncata	1	·4	—
Venus gallina	5	2	—
Venus ovata	3	1·2	—
Dosinia lupina	5	2	—
Corbula gibba	2	·8	—
Bullinella cylindracea	8	3·4	1
Buccinum undatum	1	·4	—
Actæon tornatilis	—	—	1
Nassa reticulata	—	—	1
Echinocardium cordatum	2	·8	6
Amphiura filiformis	144	57·6	72
Ophiura ciliaris	12	4·8	—
Ophiothrix fragilis	—	—	1
Cucumaria sp.	—	—	1
Decapoda larvæ	3	1·4	6
Amphipoda	10	4	3
Diastylis sp.	10	4	2
Iphinoe trispinosa	1	·4	—
Caprellidæ	1	·4	—
Pycnogonida	1	·4	—

	Conical Dredge.		Bottom Sampler.
	No. per 1 haul.	No. per 2/5 haul. (calculated).	No. per 4 dips.
Corystes cassivelaunus	1	·4	—
Portunus sp.	4	1·6	—
Owenia fusiformis	16	6·4	8
Nephthys sp.	10	4	4
Sthenelais limicola	4	1·6	2
Polynoinæ	10	4	4
Polychaeta sandy tubes	←	fragments.	→
Ophriodromus flexuosus	—	—	1
Phyllodocidæ	—	—	2
Pectinaria sp.	—	—	1
Polychaeta indet.	←	fragments.	→
Cryptocœlis alba	2	·8	2
Nemertinea	—	—	1

It would probably be unwise to pass too critical a judgment with the data of a single experiment of this kind, but the figures do show that the conical dredge is capable of taking a good sample under favourable circumstances, and will give a good idea of the general community formation. In this particular instance it has captured more species than the bottom-sampler, while none which are important items in the bottom-sampler hauls are missing. Two interesting facts were observed which are not obvious from the tables. If age, as revealed by size, is taken into account, then a greater proportion of " O " group, *Syndosmya alba*, was taken by the conical dredge than by the bottom-sampler. This may indicate that the scraping action of the dredge when in tow may result in the capture of a relatively too high number of the surface animals ? In the second place, the specimens of *Amphiura filiformis* obtained by the dredge were all badly broken, much more so than one would have expected notwithstanding the extreme ease with which these animals break up ordinarily. This may also be explained by the method of working, and serves to illustrate the advantage held by the bottom-sampler that it will bring up in excellent condition delicate organisms which would almost certainly be smashed by the dredge. Specimens of *Corymorpha nutans*, *Virgularia mirabilis*, and *Cryptocœlis alba* have been obtained in splendid condition during recent months.

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VALUATION LISTS.

PLYMOUTH SOUND. VF STATIONS.

No. 23.	Per ½ m².	No.
Nucula radiata		1
Tellina pusilla		16
Lutraria oblonga (juv.)		2
Spisula elliptica (juv.)		5
Dosinia exoleta		3
Dosinia lupina		8
Venus fasciata		3
Venus ovata		5
Tapes virgineus		1
Gari tellinella		1
Ensis arcuata (juv.)		1
Saxicava arctica		1
Echinocyamus pusillus		1
Urothoe marina		6
Hippomedon sp.		1
Nototropis vedlomensis		1
Leucothoe spinicarpa		1
Schizopoda		2
Nephthys sp.		3
Lanice conchilega		1
Terebellidæ		1
Polychaete tubes		several
Ascididæ with hydroids		2

Off New Grounds Buoy. Shelly gravel. June 22nd, 1922.

No. 35.	Per ½ m².	No.
Nucula radiata		1
Barbatia lactea		1
Lima loscombi		1
Lutraria oblonga (juv.)		57
Tellina pusilla		2
Tellina crassa		1
Spisula elliptica (juv.)		287
Dosinia exoleta		3
Venus fasciata		20
Venus casina		1
Cardium nodosum		2
Gari tellinella		1
Corbula gibba		1
Solecurtus antiquatus		1
Ensis arcuata (juv.)		9
Natica alderi		1
Echinocyamus pusillus		3
Asterias sp. (juv.)		1
Corystes cassivelaunus (juv.)		1
Eupagurus sp. (juv.)		2
Glycera sp.		3
Lumbriconereis sp.		1
Terebellidæ		1
Ampharetidæ		1
Ammodytes lanceolatus (juv.)		1
Actinia		1

West Channel off Breakwater Lighthouse. Coarse shelly gravel with some stones. July 5th, 1922.

PLYMOUTH SOUND. VF STATIONS—*continued.*

No. 47. Per ½ m².	No.
Glycimeris glycimeris	2
Lutraria oblonga (juv.)	9
Tellina pusilla	38
Tellina crassa	1
Spisula elliptica (juv.)	425
Dosinia exoleta	8
Venus fasciata	23
Venus ovata	11
Tapes virgineus	4
Cardium nodosum	3
Gari tellinella	2
Solecurtus antiquatus	1
Ensis arcuata (juv.)	15
Thracia villosiuscula	1
Echinocyamus pusillus	3
Leptocheirus hirsutimanus	1
Palæmonid	1
Glycera sp.	2
Lumbriconereis sp.	1
Sabellid	1
Aphroditidæ	1

Between New Grounds and Queen's Grounds Buoys. Coarse shelly gravel. July 25th, 1922.

No. 54. Per ⅕ m².	No.
Nucula radiata	4
Glycimeris glycimeris	1
Lutraria oblonga (juv.)	2
Tellina pusilla	21
Spisula elliptica (juv.)	83
Dosinia exoleta	5
Venus fasciata	9
Venus ovata	21
Tapes virgineus	1
Cardium nodosum	3
Gari tellinella	4
Corbula gibba	2
Solecurtus scopula	2
Ensis arcuata (juv.)	1
Echinocyamus pusillus	3
Portunus pusillus	1
Leptocheirus hirsutimanus	1
Conilera cylindracea	1
Glycera sp.	1
Polychaete tube	1

Midway between New Grounds and Queen's Grounds Buoys. Coarse shelly gravel. September 19th, 1922.

No. 89. Per ½ m².	No.
Tellina pusilla	1
Tellina donacina	1
Spisula elliptica (juv.)	17
Gari tellinella	1
Ensis sp.	1
Pontocrates arenarius	1
Nephthys sp.	2

Off Bovisand Pier. Fine shell gravel. February 20th, 1923.

No. 90. Per ⅕ m².	No.
Nucula radiata	1
Tellina crassa	1
Spisula elliptica (juv.)	5
Venus fasciata	2
Ensis arcuata (juv.)	1
Urothoe marina	3
Hippomedon sp.	1
Pontocrates arenarius	1
Glycera sp.	2
Polychaete tubes	3

Off New Grounds Buoy. Shelly gravel. February 20th, 1923.

PLYMOUTH SOUND. VF STATIONS—*continued.*

No. 91.	Per $\frac{1}{5}$ m².	No.
Spisula elliptica (juv.)		10
Venus fasciata		3
Venus ovata		1
Gari tellinella		1
Urothoe marina		1
Glycera sp.		2

Midway between New Grounds and Queen's Grounds Buoy. Shelly gravel. February 20th, 1923.

No. 92.	Per $\frac{1}{5}$ m².	No.
Nucula radiata		1
Lutraria oblonga (juv.)		2
Spisula elliptica (juv.)		42
Dosinia exoleta		1
Venus fasciata		6
Gari tellinella		1
Leptocheirus hirsutimanus		1
Polychaete indet.		1

West Channel. Coarse shelly gravel. February 20th, 1923.

PLYMOUTH SOUND. MIXED VF AND VG STATIONS.

No. 29.	Per $\frac{1}{2}$ m².	No.
Nucula nitida		1
Syndosmya alba		1
Tellina pusilla		1
Lutraria elliptica (juv.)		14
Spisula elliptica (juv.)		5
Spisula subtruncata		2
Venus ovata		1
Tapes virgineus		1
Cardium echinatum (juv.)		1
Cardium nodosum		1
Cultellus pellucidus (et juv.)		11
Ensis ensis (juv.)		14
Ensis arcuata (juv.)		23
Schizopoda		1
Nephthys sp.		2
Lumbriconereis sp.		3
Goniada maculata		2
Lanice conchilega (small)		4
Melinna adriatica (tubes)		4
Cirratulids (small)		2

Off Melampus Buoy. Mixed gravel, sand, and mud. June 26th, 1922.

No. 37.	Per. $\frac{1}{2}$ m².	No.
Lucina borealis (juv.)		1
Spisula elliptica (juv.)		13
Spisula subtruncata		1
Dosinia lupina		1
Dosinia exoleta		1
Venus fasciata		1
Venus casina		1
Venus ovata		1
Tapes virgineus		3
Cardium echinatum		1
Corbula gibba		1
Cultellus pellucidus (et juv.)		13
Ensis ensis (juv.)		2
Ensis arcuata (juv.)		10
Leptocheirus hirsutimanus		1
Nephthys sp.		3
Lumbriconereis sp.		2
Polynoid		1
Polychaete tubes		3
Nemertini		1

Off Melampus Buoy. Mixed shelly gravel and sand. July 10th, 1922.

PLYMOUTH SOUND. STATIONS WHERE EcVg MUD IS DOMINANT.

No. 24. Per ½ m².

	No.		No.
Nucula nitida	6	Synaptidæ	3
Lucina spinifera	2		
Thyasira flexuosa	83		
Montacuta bidentata	5		
Syndosmya alba	13	Melinna adriatica	many
Syndosmya nitida	4	Lumbriconereis sp.	many
Tellina donacina	1	Cirratulidæ (small)	frequent
Lutraria elliptica (juv.)	1	Notomastus latericeus	fragments
Venus gallina	1	Goniada maculata	15
Corbula gibba	1	Nephthys sp.	2
Solecurtus antiquatus	1	Glycera sp.	2
Cultellus pellucidus	3	Marphysa sp. (juv.)	1
		Polynoinæ	1
Philine aperta	1	Chlorhæmidæ	1

Jennycliff Bay. Off Inner Hospital Ship. Black mud. June 22nd, 1922.

No. 25. Per ½ m².

	No.		No.
Nucula nitida	25	Galathea sp. (juv.)	1
Thyasira flexuosa	43		
Montacuta bidentata	2	Melinna adriatica	many
Syndosmya alba	12	Lumbriconereis sp.	many
Spisula subtruncata	1	Cirratulidæ	5
Venus gallina	1	Notomastus latericeus	fragments
Venus ovata	1	Goniada maculata	8
Cardium echinatum (juv.)	1	Nephthys sp.	2
Cardium nodosum	1	Glycera sp.	3
Corbula gibba	1	Marphysa sp. (juv.)	4
Cultellus pellucidus	3	Nereis sp.	2
		Magelona papillicornis	6
Philine aperta	2	Maldanidæ	5
		Polychaetes indet.	fragments
Synaptidæ	2	Nemertini	1

Jennycliff Bay. Off Outer Hospital Ship. Black mud with some sand. June 26th, 1922.

PLYMOUTH SOUND. STATIONS WHERE EcVc MUD IS DOMINANT—*contd.*

No. 30	Per ½ m².	No.
Lucina borealis		2
Thyasira flexuosa		3
Montacuta bidentata		5
Syndosmya alba		25
Lutraria elliptica (juv.)		13
Venus gallina		4
Venus verrucosa		1
Tapes virgineus		4
Tapes pullastra		32
Cardium fasciatum		1
Gari ferrœnsis		1
Mya truncata		7
Corbula gibba		8
Cultellus pellucidus		4
Calyptræa chinensis		7
Antedon bifida		1
Eupagurus sp. (juv.)		1
Portunus sp. (juv.)		1
Melinna adriatica		many
Cirratulidæ (small)		many
Nephthys sp.		14
Lumbriconereis sp.		6
Goniada maculata		3
Magelona papillicornis		1
Nereis sp.		5
Marphysa sp.		2
Sthenelais sp.		1
Polynoinæ		1
Notomastus latericeus		1
Nemertini		1
Cereus pedunculatus		4
Sagartia sp.		2

Midway between Mallard Buoy and Batten Breakwater. Black mud with clinker. June 26th, 1922.

No. 62.	Per ½ m².	No.
Nucula nitida		3
Modiolaria marmorata		1
Lucina borealis		10
Thyasira flexuosa		10
Montacuta bidentata		1
Syndosmya alba		17
Dosinia lupina		2
Tapes virgineus		3
Tapes pullastra		35
Tapes perforans		1
Cardium fasciatum		3
Corbula gibba		34
Mya truncata (juv.)		20
Solecurtus antiquatus		2
Saxicava rugosa		1
Goniodoris castanea		1
Antedon bifida (juv.)		8
Ophiura sp.		1
Cucumaria elongata		1
Portunus sp. (juv.)		2
Carcinus maenas		1
Lysianassa ceratina		9
Melinna adriatica		6
Cirratulidæ		1
Nephthys sp.		14
Lumbriconereis sp.		3
Goniada maculata		5
Nereis sp.		7
Polynoinæ		2
Sthenelais sp.		2
Notomastus latericeus		1
Nemertini		1
Ascididæ		several

Midway between Mallard Buoy and Batten Breakwater. Black mud with clinker. October 26th, 1922.

PLYMOUTH SOUND· STATIONS WHERE EcVG MUD IS DOMINANT—*contd.*

No. 36. Per ½m².

	No.		No.
Thyasira flexuosa	1	Cirratulidæ (small)	many
Syndosmya alba	34	Nephthys sp.	7
Lutraria elliptica (juv.)	2	Lumbriconereis sp.	many
Cultellus pellucidus	1	Goniada maculata	3
Nassa reticulata	1	Nereis sp.	6
Synaptidæ	1	Phyllodocidæ	1
Carcinus maenas (juv.)	2	Polychaete sp. (indet.)	1
Melinna adriatica	many	Nemertine	1
		Zoantharia	2

Millbay Docks. Black mud. July 10th, 1922.

No. 61. Per 1 m².

	No.		No.
Nucula nitida	1	Melinna adriatica	many
Lucina borealis	1	Lumbriconereis sp.	10
Thyasira flexuosa	23	Cirratulidæ	2
Syndosmya alba	1	Notomastus latericeus	fragments
Dosinia lupina	1	Goniada maculata	5
Cultellus pellucidus	2	Nephthys sp.	1
Philine aperta	1	Owenia fusiformis (tube)	1
		Maldanidæ	3
Pycnogonida	1	Myxicola (tube)	1
Porcellana longicornis	1	Nemertini	1

Jennycliff Bay. Off Inner Hospital Ship. Black mud. October 26th, 1922.

PLYMOUTH SOUND. MIXED EcVG MUD AND b STATIONS.

No. 60. Per ½ m².

	No.		No.
Nucula nitida	1	Venus ovata	1
Lucina borealis	1	Solecurtus antiquatus	3
Thyasira flexuosa	13	Cultellus pellucidus	9
Syndosmya alba	1	Melinna adriatica	frequent
Spisula subtruncata	1	Lumbriconereis sp.	frequent
Dosinia lupina	7	Notomastus latericeus	fragments.

Midway between Duke Rock Buoy and No. 1 Anchorage Buoy. Sandy mud. October 26th, 1922.

PLYMOUTH SOUND. MIXED EcVc MUD AND b STATIONS—*continued.*

No. 26. Per $\frac{1}{2}$m².

	No.		No.
Nucula nitida	11	Schizopoda	1
Lucina borealis	3	Isopoda	1
Thyasira flexuosa	28		
Montacuta bidentata	2	Melinna adriatica	many
Syndosmya alba	14	Lumbriconereis sp.	ca. 10
Tellina fabula	2	Nephthys sp.	3
Spisula subtruncata	1	Glycera sp.	3
Lutraria elliptica (juv.)	6	Magelona papillicornis	1
Dosinia lupina (et juv.)	8	Nereis longissima	1
Venus ovata	12	Myxicola (tube)	1
Tapes virgineus	1	Polychaete tubes (sp. indet.)	fragments
Corbula gibba	24		
Mya truncata (juv.)	1		
Cultellus pellucidus	10	Nemertini	1
Portunus sp. (juv.)	1	Virgularia mirabilis	1

Off Duke Rock Buoy. Muddy sand. June 26th, 1922.

No. 32. Per $\frac{1}{2}$ m².

	No.		No.
Nucula nitida	8	Ensis ensis (juv.)	3
Modiolaria marmorata	1		
Lucina spinifera	1	Helcion pellucida	1
Thyasira flexuosa	55		
Montacuta bidentata	1	Synaptidæ	2
Diplodonta rotundata	1		
Syndosmya alba	54	Melinna adriatica	many
Syndosmya nitida	6	Lumbriconereis sp.	many
Spisula subtruncata	1	Nephthys sp.	17
Lutraria elliptica (juv.)	14	Glycera sp.	2
Dosinia lupina	3	Goniada maculata	1
Venus gallina	1	Owenia fusiformis	2
Venus ovata	23	Pectinaria sp.	1
Tapes virgineus	4	Notomastus latericeus	6
Cardium echinatum	1	Polychaete sandy tubes	frequent
Mya truncata (juv.)	2		
Corbula gibba	13	Nemertinea	1
Solecurtus antiquatus	8	Cryptocœlis alba	1
Cultellus pellucidus	37	Virgularia mirabilis	1

Midway between Duke Rock Buoy and No. 1 Anchorage Buoy. Sandy mud. July 5th, 1922.

PLYMOUTH SOUND. VG STATION.

No. 38. Per ½ m².

	No.		No.
Nucula nitida	5	Synaptidæ	1
Lucina borealis	1		
Thyasira flexuosa	28	Nika edulis	1
Syndosmya alba	42		
Lutraria elliptica (juv.)	2	Melinna adriatica	frequent
Spisula elliptica (juv.)	2	Lumbriconereis sp.	frequent
Mactra stultorum	1	Nephthys sp.	5
Venus ovata	1	Goniada maculata	2
Cardium exiguum	1	Magelona papillicornis	2
Corbula gibba	1	Sthenelais sp.	1
Cultellus pellucidus	72	Polynoinæ	2
Ensis ensis (juv.)	1	Notomastus latericeus	fragments
Philine aperta	2	Sagartia coccinea	1

Middle of Sound. Muddy sand. July 10th, 1922.

OUTSIDE WATERS. SPVF STATIONS.

No. 111. Per ⅓ m².

	No.		No.
Tellina crassa	1	Ampelisca sp.	1
Tellina pusilla	2	Lysianassidæ	1
Venus fasciata	1		
Venus ovata	3	Nephthys sp.	1
Tapes virgineus	2	Lumbriconereis sp.	1
Gouldia minima	1	Chaetopterus variopedatus (tube)	1
Echinocyamus pusillus	1	Terebellidæ	2
		Polynoinæ	1
Portunus pusillus	1	Cryptocoelis alba	1

Eddystone, S.S.E. ½ E., 1 mile. Broken shells. June 26th, 1923.

No. 112. Per ⅓ m².

	No.		No.
Nucula radiata	1	Decapoda larvæ	1
Tellina pusilla	2	Schizopoda	1
Venus ovata	1		
		Lanice conchilega (tubes)	2
Echinocyamus pusillus	1	Hyalinœcia sicula	1
Upogebia sp. (juv.)	1	Amphioxus lanceolatus	2

Eddystone, S.S.E. ½ E., 3 miles. Shelly gravel. June 26th, 1923.

OUTSIDE WATERS. SPVF STATIONS—*continued.*

No. 14. Per ½ m².

	No.		No.
Venus ovata	1	Urothoe marina	1
Solecurtus scopula	1	Monoculodes carinatus	1
Echinocyamus pusillus	2	Polygordius sp.	1
Ophiothrix fragilis	1	Lanice conchilega (tubes)	fragments
Ophiocoma nigra	1		
Asterias rubens	1	Amphioxus lanceolatus	1

Erme Head, N.E. by E., 2 miles. Clean shell gravel.
June 9th, 1922.

No. 20. Per 1 m².

	No.		No.
Nucula radiata	4	Pontocrates arenarius	1
Glycimeris glycimeris	7	Ampelisca typica	4
Lima loscombi	4	Ampelisca brevicornis	1
Tellina crassa	1	Nototropis vedlomensis	1
Spisula elliptica (juv.)	2		
Venus fasciata	21	Polygordius sp.	fragments
Venus ovata	13	Chaetopterus variopedatus (tubes)	4
Tapes virgineus	18	Glycera sp.	13
Gouldia minima	11	Lumbriconereis sp.	4
Cardium fasciatum	2	Polynoinæ	6
Gari tellinella	4	Pectinaria sp.	2
Cultellus pellucidus	1	Lanice conchilega	4
Thracia villosiuscula	1	Onuphis brittanica	1
Natica alderi	1	Nerine sp.	1
		Notomastus latericeus	1
Spatangus purpureus (juv.)	1		
Echinocyamus pusillus	10	Cryptocœlis alba	1
		Nemertini	2
Porcellana longicornis	4		
Portunus pusillus	4	Aphroceras sp.	1
Eurynome aspersa	1	Cellaria sp.	fragments
Galathea sp. (juv.)	2	Corymorpha nutans	1
Ebalia sp.	2		
Decapoda postlarvæ	4	Amphioxus lanceolatus	9

Eddystone, S.S.E. ½ E. ½ mile. Clean shell gravel.
June 20th, 1922.

OUTSIDE WATERS. SPVF STATIONS—*continued.*

No. 81. Per ½ m²	No.
Glycimeris glycimeris	24
Tellina crassa	3
Tellina pusilla	1
Venus fasciata	23
Venus ovata	7
Tapes virgineus	3
Gouldia minima	29
Cardium nodosum	2
Cardium norvegicum	1
Gari tellinella	2
Solecurtus scopula	1
Thracia villosiuscula	1
Echinocardium flavescens (juv.)	1
Echinocyamus pusillus	3
Portunus pusillus	2
Ebalia tuberosa	1
Ampelisca typica	1
Maera sp.	2
Polygordius sp.	fragments
Glycera sp.	8
Polynoinæ	1
Lumbriconereis sp.	1
Aphroceras sp.	1
Amphioxus lanceolatus	18

Eddystone, S.S.E. ½ E. ½ mile. Clean shell gravel. January 25th, 1923.

No. 95. Per ½ m².	No.
Nucula radiata	1
Glycimeris glycimeris	7
Tellina crassa	4
Tellina pusilla	4
Spisula elliptica (juv.)	2
Venus fasciata	7
Venus ovata	4
Tapes virgineus	4
Gouldia minima	5
Gari tellinella	11
Echinocardium flavescens	1
Echinocyamus pusillus	8
Cucumaria sp.	1
Ophiuroid (juv.)	1
Atelocyclus (juv.)	1
Zoæa	1
Isopoda	1
Ampelisca spinipes	2
Ampelisca sp.	1
Maera sp.	3
Gammaridae	2
Glycera sp.	4
Lumbriconereis sp.	1
Chlorhæmids	2
Polynoinæ	1
Polygordius sp.	1
Corymorpha nutans	8
Amphioxus lanceolatus	9

Eddystone, S.S.E. ½ E. ½ mile. Clean shelly gravel. May 9th, 1923.

OUTSIDE WATERS. SPVF STATIONS—*continued.*

No. 102. Per $\frac{1}{10}$ m².	No.
Glycimeris glycimeris	1
Tellina donacina	1
Venus fasciata	9
Venus ovata	7
Tapes virgineus	2
Cardium nodosum	7
Gari tellinella	1
Solecurtus scopula	1
Echinocyamus pusillus	2
Ophiura sp.	1
Ampelisca sp.	1
Maera sp.	1
Polynoinæ	1
Nephthys sp.	1
Owenia fusiformis	1
Polychaetes indet.	fragments

Knight Errant Buoy, N.N.W. $\frac{1}{4}$ mile. Coarse shell gravel with some silt. June 5th, 1923.

No. 52. Per $\frac{1}{2}$ m².	No.
Tellina pusilla	3
Tellina crassa	1
Lutraria oblonga (juv.)	2
Spisula elliptica (juv.)	47
Dosinia sp. (juv.)	8
Venus fasciata	3
Venus ovata	1
Gari tellinella	1
Ensis arcuata (juv.)	2
Echinocyamus pusillus	1
Eupagurus sp. (juv.)	1
Cirolana gallica	1
Pontocrates arenarius	1
Glycera sp.	1

Breakwater Light, E. by N. $\frac{1}{2}$ N., $\frac{3}{4}$ mile. Small gravel with shell fragments and pieces of shale. July 31st, 1922.

August 14th, 1922. Per $\frac{1}{10}$ m².

(b)	No.
Glycimeris glycimeris	3
Tellina pusilla	1
Venus fasciata	4
Venus ovata	1
Venus casina	1
Echinocyamus pusillus	1 (many dead)
Ampelisca spinipes	1
Nephthys sp.	1
Syllidæ	1
Amphioxus lanceolatus	1

Eddystone, S.W. $\frac{3}{4}$ S., $1\frac{1}{2}$ miles. Muddy coarse shell gravel. August 14th, 1922.

(c)	No.
Glycimeris glycimeris	1
Venus ovata	1
Cultellus pellucidus	3
Ampelisca spinipes	1
Nephthys sp.	1
Lanice conchilega (tube)	1

Mewstone, E.N.E. Tregantle, N. by E. $\frac{1}{4}$ E. Mixed sand, shells, and coarse material. August 14th, 1922.

OUTSIDE WATERS. SpVf STATIONS—*continued.*

No. 65. Per ½ m².

	No.		No.
Nucula radiata	3	Ampelisca typica	1
Syndosmya alba	30	Ampelisca brevicornis	1
Tellina pusilla	2	Urothoe marina	2
Venus ovata	2		
Cultellus pellucidus	9		
		Nephthys sp.	3
Natica alderi	1	Glycera sp.	2
		Goniada maculata	1
Echinocymus pusillus	1	Lumbriconereis sp.	1
		Owenia fusiformis	2
Nika edulis	1	Cirratulidæ	2
Diastylis sp.	1	Lanice conchilega (tubes)	2
Iphinoe sp.	1	Cryptocœlis alba	1

Erme Coast Guard Station, N.E. northerly. Borough Island, E. Fine shell gravel. October 31st, 1922.

No. 78. Per ⅓ m².

	No.
Nucula radiata	1
Venus fasciata	1
Cardium norvegicum	1
Natica alderi	1
Spatangus purpureus	1
Lumbriconereis sp.	2

Mewstone, N.N.W. 1⅓ miles. Shelly gravel with some mud. January 18th, 1923.

No. 87. Per ½ m².

	No.
Nucula radiata	2
Venus ovata	1
Gari tellinella	1
Spatangus purpureus	1
Synaptidæ	1
Portunus pusillus	2
Polygordius sp.	fragments
Glycera sp.	1
Polynoinæ	1
Amphioxus lanceolatus	2

Mewstone, S. 1½ miles. Shelly gravel. February 14th, 1923.

OUTSIDE WATERS. Vg STULT + Ec STATIONS.

No. 12. Per 1 m².

	No.
Mactra stultorum	2
Lutraria elliptica (juv.)	30
Venus gallina	1
Gari ferrœnsis	1
Corbula gibba	1
Cultellus pellucidus	1
Natica alderi	1
Ophiothrix fragilis	2
Amphiura filiformis	2
Corystes cassivelaunus (juv.)	2
Portunus sp. (juv.)	1
Schizopoda	1
Haplostylis normani	1
Iphinoe trispinosa	2
Pseudocuma similis	1
Diastylis sp.	6
Bathyporeia pelagica	9
Bathyporeia guilliamsoniana	1
Leucothoe sp.	1
Siphonocoetes dellavallei	1
Nephthys sp.	14
Cirratulidæ	1
Lumbriconereis sp.	2
Polychaeta (sandy tubes)	frequent
Corymorpha nutans	7
Zoantharia	3

Bigbury Bay. Clean sand. June 9th, 1922.

No. 64. Per ½ m². No.

Mactra stultorum	1
Venus gallina	1
Echinocardium cordatum	1
Iphinoe trispinosa	15
Diastylis sp.	6
Bathyporeia pelagica	1
Bathyporeia guilliamsoniana	2
Hippomedon denticulatus	3
Nephthys sp.	13
Lanice conchilega	1
Magelona papillicornis	1
Owenia fusiformis	1
Phyllodocid	1
Polychaeta (sandy tubes)	fragments

Bigbury Bay. Clean sand. October 31st, 1922.

No. 86. Per ½ m² No.

Nucula nitida	1
Syndosmya alba	1
Syndosmya prismatica	1
Mactra stultorum	2
Venus gallina	2
Venus ovata	1
Corbula gibba	1
Cultellus pellucidus	1
Ensis ensis (juv.)	1
Iphinoe trispinosa	4
Diastylis sp.	1
Bathyporeia pelagica	3
Monoculodes sp.	1
Nephthys sp.	6
Sthenelais limicola	1
Magelona papillicornis	1
Polychaeta (sandy tubes)	frequent

Bigbury Bay. Clean sand. February 14th, 1923.

OUTSIDE WATERS. Vg STULT+Ec STATIONS—*continued.*

No. 8. Per 1 m².

	No.		No.
Donax vittatus (juv.)	12	Bathyporeia pelagica	3
Mactra stultorum (juv.)	6	Siphonocœtes dellavallei	1
Lutraria elliptica (juv.)	4	Leucothoe sp.	1
Dosinia lupina	3		
Venus gallina	1	Nephthys sp.	23
		Cirratulidæ	2
Portunus sp. (juv.)	2	Lanice conchilega } fragments of	
Corystes cassivelaunus (juv.)	1	Owenia fusiformis } tubes	
Schizopoda	3		
Iphinoe trispinosa	2	Corymorpha nutans	1

Whitsand Bay. Clean sand. June 7th, 1922.

No. 43. Per ½ m².	No.	No. 94. Per ½ m².	No.
Donax vittatus	3	Nucula nitida	2
Mactra stultorum	5	Mactra stultorum	5
Lutraria elliptica (juv.)	35	Spisula subtruncata	3
Dosinia lupina	1	Lutraria elliptica	3
Venus gallina	1	Venus gallina	5
Cardium echinatum	1	Meretrix chione (juv.)	5
Cultellus pellucidus	1	Corbula gibba	1
Ensis ensis (juv.)	38		
		Echinocardium cordatum	2
Echinocardium cordatum (et juv.)	43	Echinocyamus pusillus	1
		Ophiura sp. (juv.)	5
Decapoda larvæ	3		
Iphinoe trispinosa	2	Schizopoda	3
Diastylis sp.	3	Iphinoe trispinosa	1
Bathyporeia guilliamsoniana	6	Bathyporeia pelagica	5
Acidostoma sp.	1	Bathyporeia guilliamsoniana	4
		Pontocrates sp.	1
Nephthys sp.	11	Nototropis vedlomensis	1
Owenia fusiformis	1	Ceradocus semiserratus	1
		Nephthys sp.	9
Halcampa crysanthellum	3	Owenia fusiformis	1
		Polychaeta (sandy tubes)	2

Whitsand Bay. Clean sand. July 20th, 1922.

Whitsand Bay. Clean sand. February 20th, 1923.

OUTSIDE WATERS. Vg STULT+Ec STATIONS—*continued.*

No. 9. Per 1 m².

	No.		No.
Donax vittatus	2	Corystes cassivelaunus (juv.)	1
Mactra stultorum (juv.)	8	Bathyporeia pelagica	4
Lutraria elliptica (juv.)	14	Bathyporeia guilliamsoniana	4
Dosinia lupina	3	Leucothoe sp.	1
Venus gallina	7	Urothoe sp.	1
Ensis ensis (juv.)	3	Hippomedon denticulatus	1
Natica alderi	1	Nephthys sp.	24
		Magelona papillicornis	1
Astropecten irregularis	1	Polychaeta sp. indet.	fragments
		Polychaeta, sandy tubes	fragments
Portunus sp. (juv.)	1	Corymorpha nutans	4
Galathea sp. (juv.)	1	Zoantharia	2

Whitsand Bay. Clean sand. June 7th, 1922.

No. 109. Per ½ m².

	No.		No.
Nucula nitida	2	Corystes cassivelaunus (juv.)	1
Mactra stultorum	3	Portunus sp. (juv.)	1
Tellina fabula	2	Decapoda larvæ	2
Lucinopsis undata (?) (juv.)	10	Diastylis sp.	1
Dosinia lupina (juv.)	27	Bathyporeia pelagica	1
Venus gallina (juv.)	23		
Venus ovata	1	Nephthys sp.	8
Corbula gibba (juv.)	27	Magelona papillicornis	2
Gari costulata	1	Terebellidæ	1
Ensis ensis (juv.)	4	Lumbriconereis sp.	1
Natica alderi (juv.)	1	Corymorpha nutans	1
Coryphellia ruphibranchialis	1	Zoantharia	1
Echinocyamus pusillus	1	Callionymus lyra (post-larva)	1

Off Penlee Point. Clean sand. June 12th, 1923.

OUTSIDE WATERS. b+Ec+FIL. STATIONS.

No. 13.	Per ½ m².	No.
Nucula nitida		24
Thyasira flexuosa		6
Montacuta bidentata		24
Diplodonta rotundata		1
Syndosmya alba		900
Spisula subtruncata		2
Venus gallina		2
Venus ovata		1
Cardium echinatum		3
Gari ferrœnsis		1
Corbula gibba		3
Cultellus pellucidus		14
Echinocardium cordatum		3
Amphiura filiformis		110
Ophiura ciliaris		12
Ophiothrix fragilis		2
Synaptidæ		3
Corystes cassivelaunus		3
Portunus sp. (juv.)		3
Nika edulis		1
Ampelisca sp.		1
Apherusa sp.		1
Nephthys sp.		10
Sthenelais limicola		2
Owenia fusiformis		2
Glycera sp.		1
Lumbriconereis sp.		1
Polynoinæ		1
Polychaeta (sandy tubes)		fragments
Corymorpha nutans		3
Zoantharia		1

Bigbury Bay. Borough Island, N.E. Bolt Tail, S.E. by S. Silty sand. June 9th, 1922.

No. 63.	Per ½ m².	No.
Nucula nitida		20
Lucina borealis		1
Montacuta bidentata		22
Syndosmya alba		940
Syndosmya prismatica		3
Mactra stultorum		1
Venus gallina		1
Venus ovata		3
Cardium echinatum		15
Corbula gibba		3
Cultellus pellucidus		39
Natica alderi		2
Bullinella cylindracea		2
Echinocardium cordatum		6
Amphiura filiformis		36
Ophiura ciliaris		2
Corystes cassivelaunus		1
Portunus sp. (juv.)		1
Nika edulis		1
Schizopoda		1
Diastylis sp.		2
Ampelisca sp.		1
Nephthys sp.		6
Sthenelais limicola		5
Owenia fusiformis		7
Goniada maculata		1
Lumbriconereis sp.		2
Ammotrypane aulogaster		1
Pectinaria sp.		13
Phyllodocidæ		1
Polynoinæ		1
Polychaeta (sandy tubes)		fragments
Nemertinea		2
Syngnathus sp. (juv.)		1

Bigbury Bay. Borough Island, N.E. by E. Bolt Tail, S.E. ½ S. Silty sand. October 31st, 1922.

OUTSIDE WATERS. b+Ec+FIL. STATIONS—*continued.*

No. 85. Per ½ m².

	No.		No.
Nucula nitida	49	Ophiura ciliaris	10
Thyasira flexuosa	10		
Montacuta bidentata	22	Decapoda (juv.)	1
Diplodonta rotundata	1	Gammaridea	2
Syndosmya alba	323	Diastylis sp.	3
Syndosmya prismatica	6		
Spisula subtruncata	1	Nephthys sp.	2
Cardium echinatum	10	Sthenelais limicola	4
		Owenia fusiformis	12
Bullinella cylindracea	1	Goniada maculata	2
Nassa reticulata	1	Lumbriconereis sp.	1
		Pectinaria sp.	1
Echinocardium cordatum	1	Phyllodocidæ	1
Amphiura filiformis	69	Polynoinæ	2

Bigbury Bay. Borough Island, N.E. by E. Bolt Tail, S.E. by S.
Silty sand. February 14th, 1923.

No. 98. Per ⅔ m².

	No.		No.
Nucula nitida	35	Diastylis sp.	2
Thyasira flexuosa	17	Zoæa	6
Montacuta bidentata	22	Bathyporeia pelagica	2
Tellimya ferruginosa	4	Ampelisca sp.	1
Syndosmya alba	555		
Mactra stultorum (juv.)	4	Nephthys sp.	4
Cardium echinatum	13	Sthenelais limicola	2
Gari costulata	1	Owenia fusiformis	8
Cultellus pellucidus	15	Ophiodromus flexuosus	1
		Pectinaria sp. (juv.)	1
Actæon tornatilis	1	Polynoinæ	4
Bullinella cylindracea	1	Phyllodocidæ	2
Nassa reticulata	1	Polychaeta (sandy tubes)	fragments
Echinocardium cordatum	6	Polychaeta (indet.)	fragments
Cucumaria sp.	1		
Amphiura filiformis	72	Nemertinea	1
Ophiothrix fragilis	3	Cryptocoelis alba	2

Bigbury Bay. Borough Island, N.E. ½ E. Bolt Tail, S.E. by E.
Silty sand. May 30th, 1923.

OUTSIDE WATERS. b+Ec+FIL. STATIONS—*continued.*

No. 99.	Per ½ m².	No.
Nucula nitida		6
Thyasira flexuosa		1
Diplodonta rotundata		1
Syndosmya alba		88
Venus ovata		1
Cardium echinatum		2
Cultellus pellucidus		9
Ensis ensis (juv.)		1
Nudibranchiata		1
Echinocardium cordatum		2
Cucumaria sp.		1
Amphiura filiformis		9
Corystes cassivelaunus (juv.)		1
Eupagurus sp. (juv.)		1
Decapoda larvæ		1
Ampelisca sp.		1
Nephthys sp.		4
Owenia fusiformis		6
Polynoinæ		1
Polychaeta (sandy tubes)		fragments
Polychaeta (indet.)		fragments
Nemertinea		1

Bigbury Bay. Borough Island, N.E. ½ E. Bolt Tail, S.E. by S. Silty sand. May 30th, 1923.

No. 100.	Per ½ m².	No.
Nucula nitida		195
Diplodonta rotundata (juv.)		2
Montacuta bidentata		10
Syndosmya alba		292
Spisula subtruncata		4
Mactra stultorum (juv.)		5
Tellina fabula		2
Dosinia lupina (juv.)		1
Venus gallina (et juv.)		15
Venus ovata		1
Cardium echinatum		10
Gari costulata (juv.)		7
Corbula gibba (juv.)		3
Cultellus pellucidus		17
Ensis ensis (juv.)		3
Echinocardium cordatum		4
Amphiura filiformis		38
Ophiura sp. (juv.)		7
Ophiothrix fragilis		1
Portunus sp. (juv.)		2
Inachus sp. (juv.)		1
Decapoda larvæ		3
Diastylis sp.		2
Bathyporeia pelagica		4
Hippomedon denticulata		1
Nephthys sp.		2
Sthenelais limicola		1
Cirratulidæ		1
Polynoinæ		1
Aricia sp.		1
Polychaeta (sandy tubes)		fragments

Bigbury Bay. Borough Island, N. Bolt Tail, S.E. by S. ¼ S. May 30th, 1923.

OUTSIDE WATERS. b + Ec STATIONS.

No. 48. Per ½ m².

	No.		No.
Thyasira flexuosa	19	Nereis Domerelii	1
Syndosmya alba	45	Melinna adriatica	2
Tellina pusilla	1	Nephthys sp.	3
Cardium echinatum	8	Glycera sp.	2
Cyprina islandica (juv.)	4	Goniada maculata	2
Cultellus pellucidus	11	Notomastus latericeus	frequent fragments
Echinocardium cordatum (et juv.)	42	Pectinaria sp.	52
Cucumaria elongata	2	Scalibregma inflatum	3
Synaptidæ	3	Terebellidæ	7
		Polychaeta (sandy tubes)	fragments
Porcellana longicornis (juv.)	1		
Schizopoda	1		
Decapoda (juv.)	2	Nemertinea	1
Diastylis sp.	1	Cryptocoelis alba	2
Ampelisca sp.	1	Gobius sp. post larva	1

Rame Head, E. Portwrinkle, N. by E. Muddy sand. July 25th, 1922.

No. 104. Per ½ m².

	No.		No.
Nucula nitida	20	Diastylis sp.	1
Tellimya ferruginosa	1	Ampelisca sp.	7
Syndosmya alba	24		
Syndosmya prismatica	5	Nephthys sp.	7
Dosinia lupina	1	Sthenelais limicola	3
Cultellus pellucidus	33	Owenis fusiformis	3
Lyonsia norvegica	1	Goniada maculata	3
		Pectinaria sp.	2
Bullinella cylindracea	1	Lanice conchilega (tubes)	frequent
Natica alderi	1	Terebellidæ	1
		Maldanidæ (tubes)	frequent
Echinocardium cordatum	4	Polychaeta (sandy tubes)	frequent
Echinocyamus pusillus	1		
Thione sp.	1	Nemertinea	1
Anapagurus lævis	1		
Nika edulis	1	Raia clavata (dead egg capsule)	1

Borough Island, E. Revelstoke Pt., N.E. by N. Silty sand with some flaky shell fragments. June 12th, 1923.

OUTSIDE WATERS. b+Ec STATIONS—*continued*,

No. 107. Per ½ m².

	No.		No.
Nucula nitida	1	Maera sp.	3
Lucina spinifera	1		
Thyasira flexuosa	1	Nephthys sp.	4
Syndosmya alba	3	Owenia fusiformis	27
Venus gallina	2	Goniada maculata	3
Gari sp. (juv.)	1	Glycera sp.	5
Corbula gibba	4	Notomastus latericeus	fragments
Cultellus pellucidus	5	Pectinaria sp.	5
		Chlorhæmidæ	1
		Cirratulidæ	1
Echinocardium cordatum	1	Aricia sp.	1
Echinocyamus pusillus	2	Lumbriconereis sp.	1
Ophiura sp.	1	Amphicteis gunneri	1
Ophiuroidea (juv.)	4	Lanice conchilega (tubes)	several
Synaptidæ	1	Maldanidæ	fragments and tubes
		Terebellidæ	4
Anapagurus lævis	1	Tubes of Phyllochaetopterus anglica with Sertularella sp. and sandy tubes were very frequent.	
Galathea sp.	1		
Schizopoda	1		
Decapoda larvæ	2		
Diastylis sp.	10	Nemertini	1
Ampelisca sp.	28	Crystallogobius Nilssoni	1

Rame, N. Mewstone, E.N.E. Mixed mud and sand, with some shale and shell. June 12th, 1922.

August 14th, 1922 (e) Per $\frac{1}{10}$ m².

	No.		No.
Syndosmya alba	1	Eupagurus sp. (juv.)	1
Syndosmya prismatica	1		
Lutraria sp. (juv.)	1	Nephthys sp.	1
Cultellus pellucidus	2	Glycera sp.	1
		Notomastus latericeus	fragments
		Pectinaria sp.	1
		Lanice conchilega	1
Echinocardium cordatum (juv.)	11	Cirratulidæ	1

Tregantle, N. by E. ¼ E. Mewstone, E. ½ N. Silty sand with gravel and shell in fair amount. August 14th, 1922.

OUTSIDE WATERS. b+Ec STATIONS—*continued.*

No. 103. Per $\frac{1}{5}$ m².

	No.		No.
Nucula nitida	1	Diastylis sp.	1
Syndosmya alba	36	Ampelisca sp.	1
Cardium fasciatum	1	Maera sp.	2
Cultellus pellucidus	1		
		Melinna adriatica	1
Turritella communis		Notomastus latericeus	fragments
Many dead shells		Nephthys sp.	1
		Polynoinæ	1
		Terebellidæ	2
Echinocardium cordatum	6	Polychaeta indet.	fragments
Callianassa subterranea (juv.)	1	Zeugopterus punctatus (post-larva)	1
Ebalia tuberosa	1		

Downderry, N. Portwrinkle, N.E. by N. Coarse sandy mud with some shell fragments, par-ticularly Turritella. June 5th, 1923.

OUTSIDE WATERS. (b) STATIONS.

No. 50. Per $\frac{1}{2}$ m².

	No.		No.
Nucula nitida	4	Schizopoda	3
Syndosmya alba	4	Decapoda larvæ	1
Syndosmya prismatica	6	Protella phasma	3
Spisula elliptica	3	Ampelisca tenuicornis	1
Dosinia sp. (juv.)	1		
Venus gallina	1	Cellaria	fragments
Cardium echinatum	7		
Diplodonta rotundata	1	Polychaeta (sandy tubes).	
Cyprina islandica	1	Most common, including	
Corbula gibba	1	Lanice conchilega (juv.)	
Cultellus pellucidus (et juv.)	70	and Owenia fusiformis.	
		Sthenelais limicola	2
Echinocardium cordatum (juv.)	68	Pectinaria korenyi	2
Echinocyamus pusillus	8	Glycera sp.	1
Cucumaria sp.	1	Lumbriconereis sp.	1
		Phyllochaetopterus anglica (tubes)	fragments
Porcellana longicornis	2	Polychaeta indet.	fragments
Galathea sp..	1		
Nika edulis	1	Clupea sp. (post-larva)	1

Eddystone, W., 2 miles. Fine silty sand. July 31st, 1922.

OUTSIDE WATERS. (b) STATIONS—*continued.*

No. 82. Per ½ m².	No.
Nucula nitida	27
Syndosmya alba	2
Syndosmya prismatica	7
Montacuta bidentata	1
Dosinia sp. (juv.)	1
Venus gallina	2
Cardium echinatum	1
Corbula gibba	1
Cultellus pellucidus	6
Echinocardium cordatum (juv.)	3
Echinocyamus pusillus	3
Amphiura filiformis	1
Ophiura sp. (juv.)	2
Asterias rubens (juv.)	1
Diastylis sp.	2
Ampelisca sp.	1
Cellaria	fragments
Nephthys sp.	5
Sthenelais limicola	3
Pectinaria sp.	1
Owenia fusiformis	6
Polynoinæ	1
Polychaeta (sandy tubes)	fragments

Eddystone, W. by S., 3½ miles. Fine silty sand. January 25th, 1923.

August 14th, 1922 (d) Per $\frac{1}{10}$ m².	No.
Nucula nitida	1
Syndosmya alba	1
Syndosmya prismatica	6
Cardium echinatum	4
Cultellus pellucidus	43
Echinocardium cordatum (juv.)	27
Echinocyamus pusillus	4
Portunus sp. (juv.)	1
Schizopoda	1
Decapoda (juv.)	1
Ampelisca sp.	1
Cellaria	fragments
Glycera sp.	2
Pectinaria sp.	6
Owenia fusiformis	10
Cirratulidæ	1
Phyllochaetopterus anglica (tubes)	fragments
Polychaeta (sandy tubes)	many fragments

Tregantle, N. by E., ¼ E. Mewstone, E. by N., ¼ N. Silty sand. August 14th, 1922.

OUTSIDE WATERS. (b) STATIONS—*continued.*

No. 105. Per ½ m².

	No.		No.
Nucula nitida	1	Bathyporeia pelagica	3
Lucina spinifera	1	Monoculodes sp.	2
Syndosmya alba	1	Melphidipella macra	1
Syndosmya prismatica	2	Nototropis vedlomensis	1
Cultellus pellucidus	1	Monoculodes sp.	1
Echinocardium cordatum	2	Nephthys sp.	2
Echinocyamus pusillus	1	Sthenelais limicola	1
Luidia sarsi	1	Lumbriconereis sp.	1
Ophiothrix fragilis	1	Owenia fusiformis	1
		Polynoinæ	1
Portunus sp.	1	Polychaeta, tubes (mostly Lanice conchilega)	many
Anapagurus lævis	1		
Ebalia sp.	1		
Schizopoda	2	Nemertinea	1
Decapoda larvæ	2	Cellaria with hydroids fragments	
Diastylis sp.	5	Pleuronectes limanda (post-larva)	1
Caprellidæ	1	Clupea sp. (post-larva)	1
Ampelisca sp.	6		

Rame Head, N.N.W. Eddystone, W. Silty sand with flaky shell fragments. June 12th, 1923.

No. 113. Per ½ m².

	No.		No.
Nucula nucleus	1	Eurysthius sp.	3
Syndosmya alba	4		
Syndosmya nitida	2	Sertularella with Scalpellum, and young Pecten sp.	
Syndosmya prismatica	15		
Venus gallina	2		
Gari sp. (juv.)	2	Lanice conchilega (tubes)	4
		Owenia fusiformis	8
Echinocyamus pusillus	5	Nephthys sp.	5
		Glycera sp.	1
Schizopoda	7	Ophiodromus flexuosus	1
Caprellidæ	1	Sthenelais limicola	1
Ampelisca sp.	2	Polychaeta (sandy tubes)	ca.6

Eddystone, S.S.E. Rame, E. by N. Fine muddy sand. June 26th, 1923.

OUTSIDE WATERS. EcVG MUD STATIONS.

No. 5. Per 1 m².	No.
Syndosmya alba	2
Solecurtus antiquatus	1
Corbula gibba	1
Echinocardium cordatum	1
Cucumaria elongata	7
Gonoplax rhomboides	1
Alphæus ruber	1
Callianassa subterranea (juv.)	6
Corystes cassivelaunus (juv.)	4
Porcellana longicornis (juv.)	2
Diastylis sp.	2
Melinna adriatica	many
Notomastus latericeus	many
Nephthys sp.	8
Glycera sp.	7
Magelona papillicornis	4
Aricia sp.	1
Polychaeta indet.	fragments
Nemertinea	2
Sagartia sp.	1
Clupea sp. (post-larvæ)	3
Pleuronectes limanda (post-larvæ)	2

Rame Head, E. ¼ N., 1¾ miles. Black mud. May 31st, 1922.

No. 53. Per $\frac{5}{10}$ m².	No.
Syndosmya alba	2
Cucumaria elongata	3
Synaptidæ	1
Alphæus ruber	1
Callianassa subterranea (juv.)	3
Nika edulis	1
Galathea sp. (juv.)	1
Diastylis sp.	1
Melinna adriatica	many
Notomastus latericeus	many
Nephthys sp.	1
Goniada maculata	1
Magelona papillicornis	13
Scalibregma inflatum	13
Ophiodromus flexuosus	2
Cirratulidæ	1
Sthenelais sp.	2
Polynoinæ	1
Nemertinea	1

Rame Head, E., 1½ miles. Black mud. August 11th, 1922.

No. 93.	No.
Turritella communis	2
Cucumaria elongata	2
Synaptidæ	2
Gonoplax rhomboides	2
Alphæus ruber	1
Callianassa subterranea (juv.)	8
Diastylis sp.	4
Ampelisca tenuicornis	2

Per $\frac{1}{5}$ m².	No.
Melinna adriatica	many
Notomastus latericeus	frequent
Nephthys sp.	3
Glycera sp.	1
Goniada maculata	3
Magelona papillicornis	4
Ophiodromus flexuosus	1
Cirratulidæ	1
Lumbriconereis sp. (?)	2
Nemertinea	1

Rame Head, E. ½ N. Tregantle, N. ½ E. February 20th, 1923.

OUTSIDE WATERS. V_G+TURRITELLA COMMUNIS STATIONS.

No. 96. Per ½ m².

	No.		No.
Nucula nitida	1	Diastylis sp.	1
Lucina spinifera	2	Ampelisca sp.	7
Thyasira flexuosa	1		
Solecurtus antiquatus	1		
Cultellus pellucidus	1	Melinna adriatica	1
Thracia convexa	1	Notomastus latericeus	ca15
		Nephthys sp.	3
		Glycera sp.	2
Bullinella cylindracea	1	Goniada maculata	6
Turritella communis (many living)	300	Magelona papillicornis	2
		Owenia fusiformis	1
		Ammotrypane aulogaster	1
Cucumaria elongata	4	Aricia sp.	fragments
Cucumaria sp.	1	Lumbriconereis sp.	1
Amphiura filiformis	1	Cirratulidæ	1
		Terebellidæ	3
Gonoplax rhomboides	1		
Alphæus ruber	1	Nemertinea	2

Rame Head, N.E. by E., ½ E., 1½ miles. Muddy coarse sand with some shell fragments. May 9th, 1923.

No. 84. Per ½ m².

	No.		No.
Thyasira flexuosa	1	Melinna adriatica	1
Syndosmya alba	1	Notomastus latericeus	fragments
Venus gallina	1	Nephthys sp.	10
Cultellus pellucidus	5	Glycera sp.	2
		Goniada maculata	1
Turritella communis	29	Pectinaria sp.	1
		Owenia fusiformis	1
Alphæus ruber	3	Ammotrypane aulogaster	1
Ebalia sp.	1	Terebellidæ	2
Callianassa subterranea (juv.)	1	Phyllochaetopterus anglica (tubes)	fragments
Ampelisca sp.	2		

Rame Head, N.W., ½ W. Mewstone, N.E. by E. Muddy sand with some fragments of shale and shell. January 25th, 1923.

OUTSIDE WATERS. VG + NUCULA NUCLEUS STATIONS.

No. 106. Per ½ m².

	No.		No.
Nucula nucleus	16	Decapoda larvæ	10
Modiolaria marmorata	1	Schizopoda	6
Syndosmya alba	52	Diastylis sp.	1
Venus ovata	4	Gnathia maxillaris	2
Cultellus pellucidus	2	Melphidipella macra	1
		Ampelisca sp.	11
Echinocyamus pusillus	2	Nephthys sp.	5
Ophiura sp. (juv.)	2	Glycera sp.	5
		Goniada maculata	3
Turritella communis (shells)	many	Owenia fusiformis	2
(*a*) Many empty.		Lanice conchilega	3
(*b*) Some with Phascolion strombi.		Notomastus latericeus	fragments
(*c*) Some with Anapagurus lævis.		Sthenelais sp.	1
(*d*) Some carrying Sagartia sp.		Cirratulidæ	1
		Polynoinæ	2
		Aricia sp.	1
		Terebellidæ	3
Ebalia sp.	1	Lumbriconereis	fragments
Portunus sp. (juv.)	1	Polychaeta (tubes)	several
Galathea sp. (juv.)	1	Some Cellaria present with Phyllochaetopterus tubes.	
Upogebia sp. (juv.)	1		

Rame Head, N.N.W. Mewstone, N.E. by N. Muddy sand with broken shells and coarse materials well represented. Dead Turritella shells most numerous. June 12th, 1923.

No. 6. Per 1 m².

	No.		No.
Nucula nucleus	14	Galathea sp. (juv.)	3
Astarte sulcata	5	Upogebia deltura	1
Syndosmya alba	2	Diastylis sp.	1
Tellina donacina	1	Eurystheus maculatus	1
Venus fasciata	1	Ampelisca diadema	1
Venus ovata	9	Melinna adriatica	3
		Notomastus latericeus	4
Echinus sp. (juv.)	1	Owenia fusiformis	2
Ophiactis balli	1	Glycera sp.	6
Ophiocoma nigra	4	Maldanidæ	fragments
Eurynome aspersa	1	Pallasia murata (tube)	1
Porcellana longicornis	1	Phyllodocidæ	1
Ebalia tumefacta	1	Polychaeta indet.	2

Downderry, N.N.E. Looe, N. by W., ½ W. Muddy shingle. Difficult ground for bottom-sampler. May 31st, 1922.

MR. J. R. BAKER'S HAULS WITH CONICAL DREDGE.

July–September, 1921.

LIST OF ALL SPECIES FOUND IN DEPOSITS OF MUD, with tables of the number of individuals of each species, per sample of 20 litres, in each locality.

	Near Mallard Buoy.	100 yards East of Mallard Buoy	Rum Bay.	Jennycliffe Bay.
COELENTERATA.				
Cerianthus Lloydi	3	2	—	—
POLYCHAETA.				
Phyllodoce maculata	8	2	4	—
Nereis sp.	—	2	—	—
Nephthys sp.	6	12	—	—
Lumbriconereis sp.	24	20	5	8
Marphysa Belli	6	—	1	—
Goniada maculata	8	—	17	18
Glycera sp.	—	—	1	2
Magelona papillicornis	4	—	2	—
Cirratulus cirratus	—	4	—	—
Melinna adriatica	119	96	*c.* 130	110
Capitella capitata	—	—	—	4
CRUSTACEA.				
Orchomene batei	—	2	—	—
Galathea sp.	—	—	1	—
Porcellana longicornis	1	—	—	—
Macropodia rostratus	—	—	1	—
Portunus marmoreus	—	—	1	—
Pilumnus hirtellus	—	2	—	—
GASTROPODA.				
Philine aperta	—	6	22	—
LAMELLIBRANCHIATA.				
Nucula nitida	2	—	—	2
Glycimeris glycimeris	—	2	—	—
Astarte sp.	1	—	—	—

MR. J. R. BAKER'S HAULS WITH CONICAL DREDGE—*continued.*

	Near Mollard Buoy	100 yards East of Mallard Buoy	Rum Bay.	Jennycliffe Bay.
LAMELLIBRANCHIATA (*contd.*).				
Lucina borealis	—	2	1	—
Thyasira flexuosa	12	2	2	20
Syndosmya nitida	2	16	4	6
Syndosmya alba	—	18	1	2
Spisula elliptica	—	4	—	—
Dosinia lupina	—	2	—	—
Venus gallina	5	8	4	—
Tapes sp.	2	6	—	—
Cardium sp.	—	2	1	—
Corbula gibba	—	2	—	—
Solecurtus antiquatus	—	2	—	2
Cultellus pellucidus	1	4	5	—
OPHIUROIDEA.				
Ophiura albida	—	—	1	—

LIST OF ALL SPECIES FOUND IN DEPOSITS OF SAND, with tables of the number of individuals of each species, per sample of 20 litres, in each locality.

	Whitsand Bay.	Whitsand Bay.	Eddystone bearing W. by N. about 6 miles.	Eddystone bearing W. by N. about 6 miles.	Bigbury Bay.
POLYCHAETA.					
Sthenelais boa	—	—	—	—	5
Nephthys sp.	6	13	3	6	7
Lumbriconereis sp.	—	—	—	—	1
Glycera siphonostoma	—	—	3	4	—
Owenia fusiformis	—	—	3	—	—
Lanice conchilega	—	—	4	2	—
Capitella capitata	2	—	—	—	—
Nicomache lumbricalis	—	—	1	—	—

MR. J. R. BAKER'S HAULS WITH CONICAL DREDGE—*continued.*

	Whitsand Bay.	Whitsand Bay.	Eddystone bearing W. by N. about 6 miles.	Eddystone bearing W. by N. about 6 miles.	Bigbury Bay.
CRUSTACEA.					
Ampelisca spinipes	2	—	—	2	—
Ampelisca tenuicornis	—	—	1	2	1
Maera othonis	—	—	—	2	—
Bathyporeia norvegica	12	—	—	—	—
Hippomedon denticulatus	—	1	—	—	—
Siphonœcoetes Colletti	—	—	1	—	—
Iphinoe trispinosa	2	3	—	—	1
Nika edulis	—	—	1	—	—
Galathea strigosa	—	—	1	6	—
Porcellana longicornis	—	—	1	—	—
Portunus pusillus	—	—	1	—	—
GASTROPODA.					
Nassa reticulata	—	1	—	—	—
LAMELLIBRANCHIATA.					
Donax vittatus	2	—	—	—	—
Pecten sp. juv.	—	—	1	—	—
Lucina borealis	—	—	—	2	—
Tellina donacina	—	—	1	—	—
Syndosmya prismatica	—	—	—	2	—
Spisula solida	—	—	—	—	1
Meretrix chione	2	—	—	—	—
Dosinia lupina	—	—	2	6	—
Venus gallina	2	3	—	6	7
Corbula gibba	—	—	—	—	1
Ensis ensis	—	1	—	—	3
Cultellus pellucidus	—	—	3	2	10
ECHINODERMATA.					
Amphiura filiformis	—	—	1	—	—
Ophiura albida	—	—	—	4	2
Echinocardium sp.	—	1	1	—	1
Cucumaria sp.	—	—	1	—	—

List of all Species found in Deposits of SHELL GRAVEL, with tables of the number of individuals of each species, per sample of 20 litres, in each locality.

	Eddystone bearing W. 3 miles.	Eddystone bearing W. 1½ miles.	Mewstone N. ¼ W. Yealm Pt. N.E.	"New Grounds."
Polychaeta.				
Harmothœ setosissima	—	2	—	2
Nephthys sp.	—	—	—	2
Lumbriconereis sp.	1	—	—	—
Glycera lapidum	—	2	1	2
Glycera Ehlersi	—	2	—	—
Glycera siphonostoma	—	—	1	—
Hyalonœcia sicula	2	—	1	—
Crustacea.				
Maera othonis	—	4	—	—
Conilera cylindracea	1	—	—	2
Eulima polita	—	—	1	—
Galathea sp. juv.	—	6	—	—
Porcellana longicornis	1	4	—	2
Craspedochilus onyx	—	2	—	—
Trophon muricatus	—	2	—	—
Lamellibranchiata.				
Nucula sp.	1	—	3	—
Glycimeris glycimeris	1	4	—	—
Lucina borealis	—	2	—	—
Tellina pusilla	—	—	—	4
Dosinia lupina	—	—	1	10
Venus fasciata	3	4	—	4
Gouldia minima	—	—	—	2
Tapes sp.	1	2	—	—
Cardium sp. juv.	—	—	—	4
Psammobia tellinella	1	—	1	1
Corbula gibba	—	—	—	1
Echinodermata.				
Ophiura albida	—	—	1	—
Ophiothrix fragilis	—	—	—	1
Echinus sp. juv.	1	—	—	—
Echinocyamus pusillus	1	—	1	2
Chordata.				
Amphioxus lanceolatus	4	—	2	—

Hydrographic Features of the Water in the Neighbourhood of Plymouth during the Years 1921 and 1922.

By

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Hydrographer at the Plymouth Laboratory.

With Tables I–III, and Figures 1–6 in the Text.

DATA obtained during the cruises of the s.ss. *Huxley* and *Oithona* in the years 1903 to 1906 indicated a general seasonal movement of water into and out of the mouth of the English Channel. It was found that in the autumn, somewhat sooner or later and to a greater or less extent each year, water, of the high salt content characteristic of the open Atlantic in the north of the Bay of Biscay and to the south-west of the English Channel, began to move in a north-easterly direction into the mouth of the English Channel, extending in a tongue along the centre of the Channel and into the Irish Channel, which is characterised by water of lesser salt content.

This general movement of relatively high salinity water continued during the winter until the spring or early summer, when water of lesser salinity moved southward from the Irish Channel across the mouth past Ushant, and to some extent into the English Channel; the condition in August being that water of relatively high salinity which had entered the Channel during the winter months was cut off from Atlantic water of equal salinity by a less saline water-mass extending south from the Irish Channel.*

These general movements have been deduced from the data collected during the cruises in February, May, August, and November. To accurately depict the changing conditions and follow the movement of the water year by year would require frequent observations, more or less simultaneous, over a wide area—a condition of perfection which in practice could not be obtained without the use of several ships working almost continuously and in conjunction.

* Matthews, D. J. *Physical Conditions in the English Channel*, 1904–1906. 2nd Report (Southern Area) Internat. Invs. Mar. Biol. Assoc. Cd. 4641.
Physical Conditions in the English Channel, 1906. 3rd Report (Southern Area) Internat. Invs. Mar. Biol. Assoc. Cd. 5546.
Fisheries, Ireland Sci. Invest., 1913, IV, 1914.

During this period and subsequently* considerable use has been made of surface observations of cross-Channel steamers, the mean conditions of temperature and salinity of various areas of the Channel calculated and the departure from the " mean " conditions year by year tabulated. In the central area of the Channel, roughly between Portland and the Channel Islands, it was found during the quarterly cruises† that tidal mixing was so complete that the water was nearly always at the same salinity at all depths; and, in consequence, following the change in salinity of the surface samples gave evidence of the source and movements of the changing water-masses. There is little evidence that the slight differences in salt content would *per se* prove a physiological factor affecting the fauna; it is used merely as a means of deducing the general movements of the water in which the animals live.

During 1921 two cruises and during 1922 five cruises have been made by the s.s. *Salpa*, the Stations E1, E2, E3, N1, N2, N3, E6, and E7 being worked. In addition the Station E1, ten miles south-west of the Eddystone, has been worked monthly; from these monthly data there is great promise of being able to follow in detail how the physical condition and general movements of the sea in the neighbourhood of Plymouth vary one year with another, whereas in previous years so long a time had elapsed between each quarterly cruise that quite material changes might have taken place in the intervals and remained unnoticed. This area of the sea is of particular interest, since the biological features are being followed throughout the entire year in the course of the ordinary routine of the *Salpa*.

The itinerary and times of the cruises have been arranged in co-operation with the French and Irish Fishery Departments, the former undertaking a general review of the whole area to the south-west of the British Isles; this is published, together with the full data collected by the various ships, by the Conseil Permanent pour l'Exploration de la Mer. The report for 1921‡ has just been published.

During the two years, 1921 and 1922, several points of interest concerning the movements of the water-masses and general hydrographic conditions in the neighbourhood of Plymouth have arisen, which it is not out of place to discuss at the present juncture. The data were collected by and the cruises made under the direction of the late Mr. E. W. Nelson, of Dr. W. R. G. Atkins, and of the writer.

* Jee, E. C. *Min. Agri. Fisheries. Fishery Invest.*, Vol. I, Ser. III, Parts 1–6.

† Matthews. *Physical Conditions of the English Channel.* 3rd Report Internat. Invs. Mar. Biol. Assoc.

‡ Le Danois. *Rapport Atlantique*, 1921. Conseil Perm. pour l'exploration de la mer, May, 1923.

Vertical distribution.

The diagrams (Fig. 1) showing the vertical distribution of temperature and salinity bring out two noteworthy features. From May to the end of September the water down to depths of about 25 metres is tolerably distinct from the water below, except in July, 1922, when vertical mixing had undoubtedly taken place after a spell of boisterous weather. Also, when the rapid movement of water from a water-mass of high salinity is taking place, as in October, 1921, there are formed tongues of the higher salinity water penetrating horizontally into the surrounding water more rapidly than vertical mixing occurs.

The relation between the temperature of the surface water, that is, the surface 6 to 10 in. as sampled by dipping a wooden or leather bucket, and the water immediately below at about 5 meters depth, is of particular interest, since many of the previous conclusions on the hydrography of the English Channel have been deduced from data of the surface water collected in this way.

From the end of September to April, the less sunny and more windy months of the year, the surface water is very similar to the whole mass of the water below at E1, and the same condition was found at all the other stations worked during the November, February, and March cruises, the temperature being to within one degree of that of the water at 5 metres and of the whole mass of the water below.

During the summer months, however, wide differences between the temperature of the surface and water at 5 metres may occur, particularly in calm and sunny weather, when vertical mixing is at a minimum. The difference in both temperature and salinity between the surface and the whole mass of water is still greater, as is amply shown in the vertical distribution diagrams. In fact, it shows that little can be concluded from the study of surface water data alone during these months. The following data obtained in August, 1921, at Station E1, are significant, a fall in temperature on the surface of 1·6° being experienced in seven hours and a subsequent rise of 1·6° in four hours, the tidal stream running to the westward and then back again in an easterly direction during the rise in temperature.

	Station E1.	Temp.	Salinity.
Aug. 15, 6 p.m.,	Surface water . .	16·21	35·17
10 p.m.	,, . .	15·7	35·11
Aug. 16, 1 a.m.	,, . .	14·6	35·15
5 a.m.	,, . .	16·2	35·09
8 a.m.	,, . .	16·01	35·11

A comparison of the depth of the water layers of equal temperature at the same station after the lapse of twelve hours, when the whole

mass of water will have been swept back to nearly the same position by the tidal stream, is somewhat suggestive of undulatory movements of the layers, as is thought to occur in the Norwegian Sea.* It is proposed to carry out further work on this point when opportunity occurs.

STATION E1.

August 15, 1921. 6.5 p.m. to 7.5 p.m.			August 16, 1921. 6.20 a.m. to 7.20 a.m.		
Depth.	Temp.	Salinity.	Depth.	Temp.	Salinity.
5	—	—	5	16·02	35·09
10	15·6	35·09	10	16·02	35·13
15	—	—	15	15·77	35·13
20	13·79	35·22	20	13·68	35·21
25	13·42	35·30	25	13·59	35·19
30	—	—	30	13·51	35·18
40	13·33	35·22	40	13·38	35·14
50	—	—	50	13·30	35·13
60	—	—	60	13·27	35·16
70	—	—	70	—	—

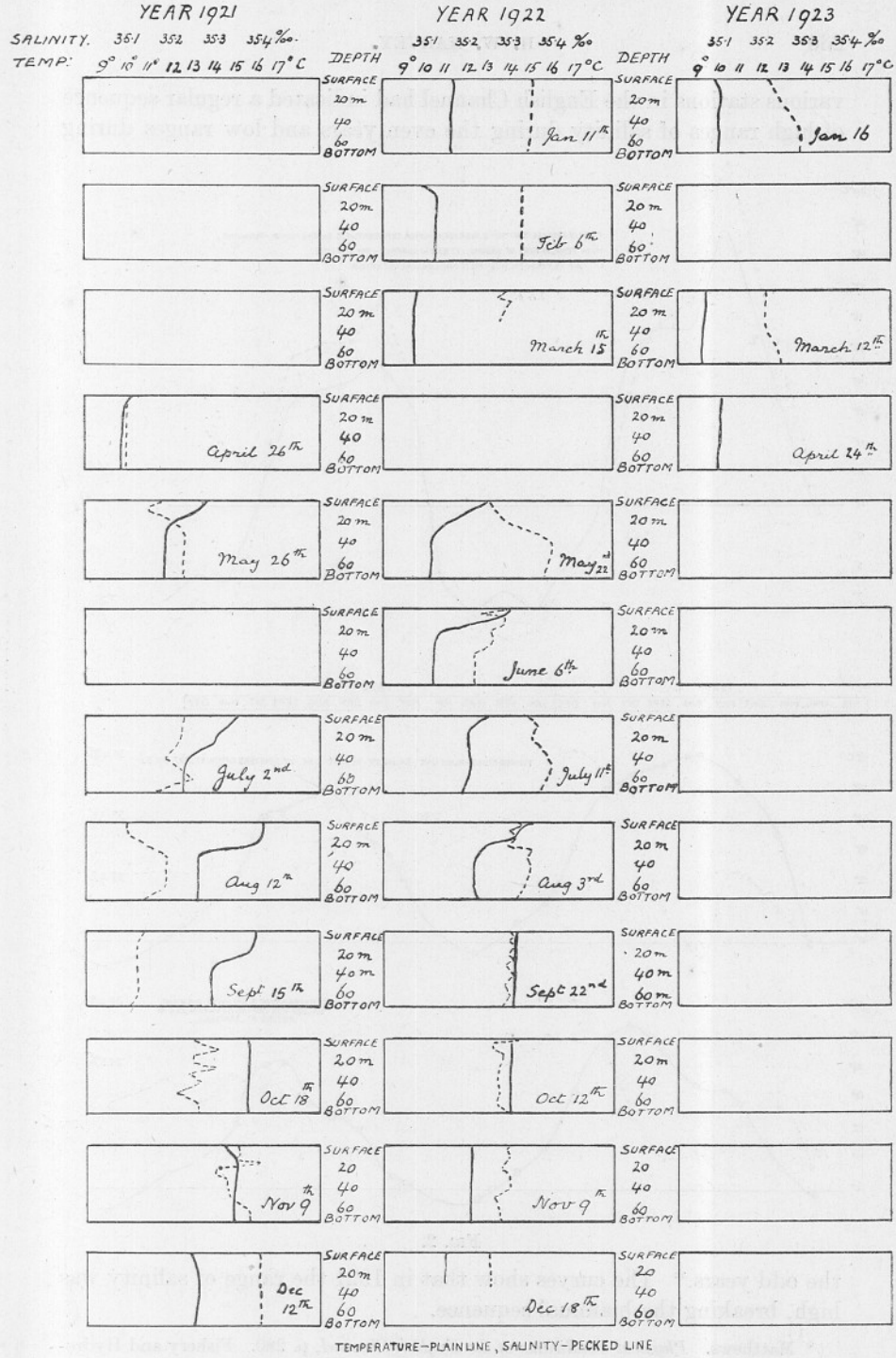
A very well-marked discontinuity of the temperature gradient was found at E1 in June and July, 1923. In July on one occasion a fall of $3\frac{1}{2}^{\circ}$ was found to occur between $12\frac{1}{2}$ and $17\frac{1}{2}$ metres; unfortunately, owing to the ship rolling, it was not possible to find the precise depths (from about 14 to 17 metres) within which the change occurred. The discontinuity layer remained for three hours at the same depth, and then during the next three hours rose about $2\frac{1}{2}$ metres, while on one occasion at a position one mile distant from E1 the discontinuity layer was 2 to 3 metres higher than at E1.

Seasonal variations at Station E1.

The average temperature and salt content of the layer of water above 25 metres was compared with that of the " deep water " below 25 metres, and further with the mean air temperature and with the temperature of the ground on Plymouth Hoe, curves being drawn to show the values month by month. The warm late autumn of 1921 is very apparent, and is coincident with a drift of relatively warm high salinity water from the south-west during October and November. This indicates that this drift not only decreased the rate of fall of temperature of the surface layers of the sea, but of the air and of the ground as well, in this way exerting a well-marked influence upon the local climate.

During the years 1903 to 1908 cruises made every three months to

* *Depths of the Ocean.* Hjort. 1912, pp. 279–280.



TEMPERATURE—PLAIN LINE, SALINITY—PECKED LINE

SALINITY & TEMPERATURE AT VARYING DEPTHS AT STATION E1.

FIG 1.

various stations in the English Channel had indicated a regular sequence of high ranges of salinity during the even years and low ranges during

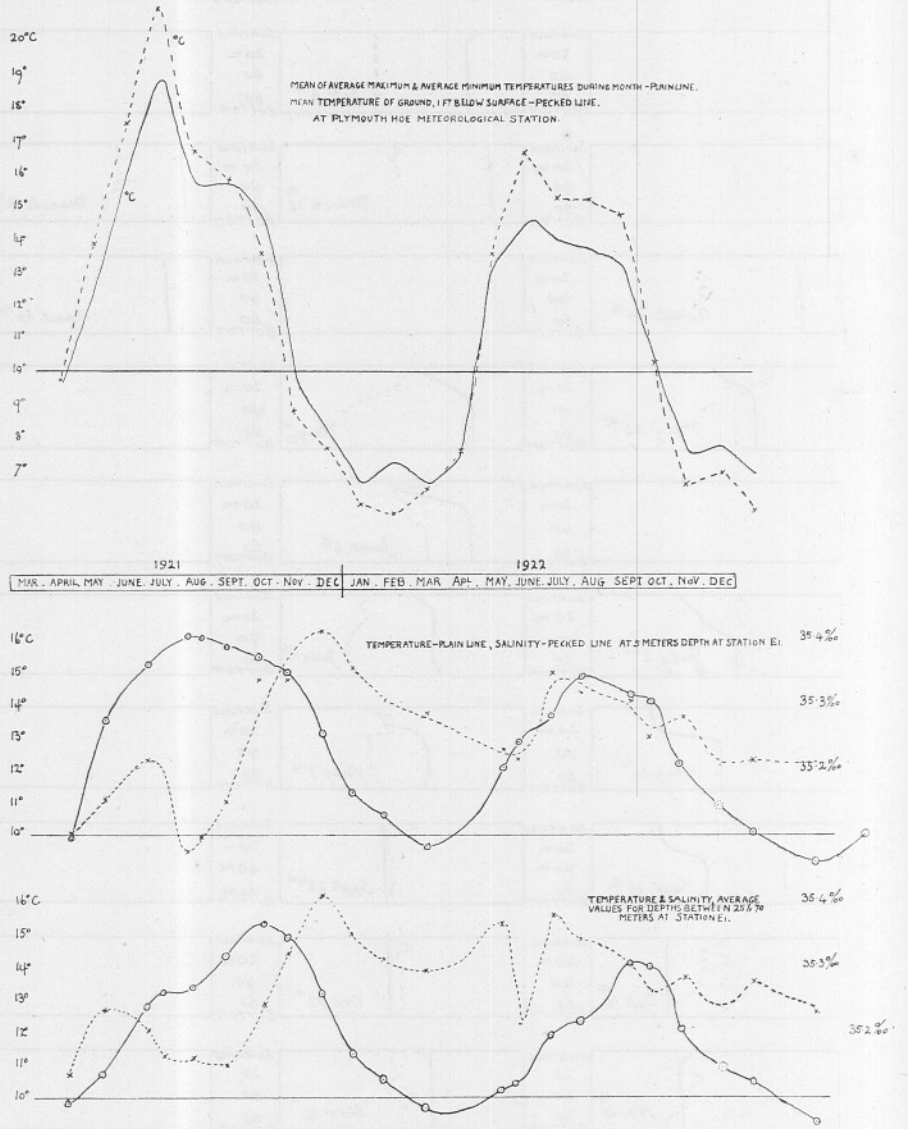


FIG. 2.

the odd years.* The curves show that in 1921 the range of salinity was high, breaking the biannual sequence.

* Matthews. *Physical Conditions of the English Channel*, p. 280. Fishery and Hydrographical Investigations in the North Sea and Adjacent Waters, 1906 to 1908.

During 1921, in July, there was a marked check in the increase of temperature of the "deep water" at E1, coincident with a fall in salinity.

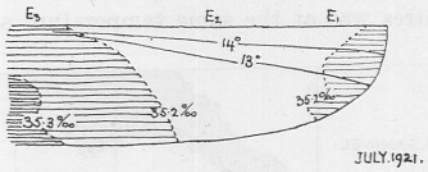


FIG. 3.

Reference to Table I and the sectional diagram from Plymouth to Ushant indicates that a tongue of slightly less saline and colder water from the south of the Irish Channel had extended up the centre of the English Channel.

TABLE I.

YEAR 1921. Average Temperature and Salinity of Water below 25 meters.

Station N_2 49° 45′ N. 6° 21′ W.	July	11·23° C. 35·11°/$_{oo}$
	Nov.	13·44° C. 35·26°/$_{oo}$
Station N_1 49° 14′ N. 5° 51′ W.	July	11·10° C. 35·22°/$_{oo}$
Station E_1 50° 02′ N. 4° 22′ W.	July	12·8° C. 35·20°/$_{oo}$
	Nov.	14·97° C. 35·32°/$_{oo}$
Station E_2 49° 27′ N. 4° 42′ W.	July	12·37° C. 35·16°/$_{oo}$
	Nov.	14·51° C. 35·34°/$_{oo}$
Station E_3 48° 34′ N. 5° 13′ W.	July	12·82° C. 35·30°/$_{oo}$
	Nov.	Ca35·5°/$_{oo}$

A very rapid rise in salinity commenced early in September, and the temperature of the "deep water" continued to rise until unusually late (mid October), after which it fell slowly while the salinity continued to rise. The surface layers attained their maximum temperature earlier at 5 metres in August, or about one month after the maximum ground and air temperature, and fell slowly until the end of November.

A surface sample of water taken off Ushant (E3) in November had a salinity of 35·48 per cent, considerably more saline than the water off the Scillies (N2), and it may be presumed that the water drifting into the Plymouth area during this period of rapid rise in salinity was the north-westerly drift of warm water from the Bay of Biscay (transgression estivale des eaux chauds).*

At the end of October the ground temperature on Plymouth Hoe was 11°, or 3° higher than at the same time in the following year, while the

* Le Danois. Cons. Perm. Int. pour l'exploration de la mer. *Rapport Atlantique.* 1921.

temperature of the deep water at E1 was 15°, 2° higher than in the following year.

During the year 1922, at the end of April, E1 water both at 5 metres and below 25 metres was at the same temperature as in the previous

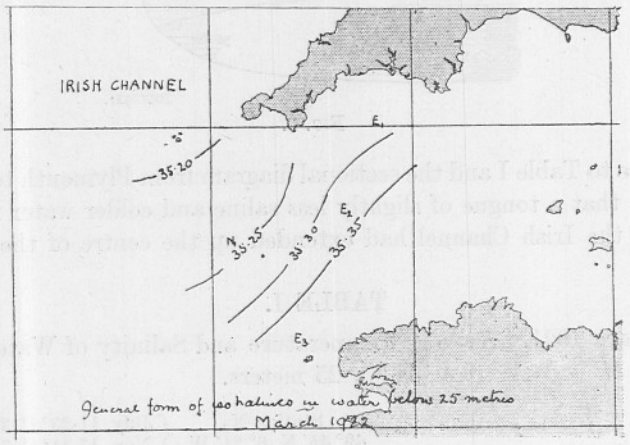


Fig. 4.

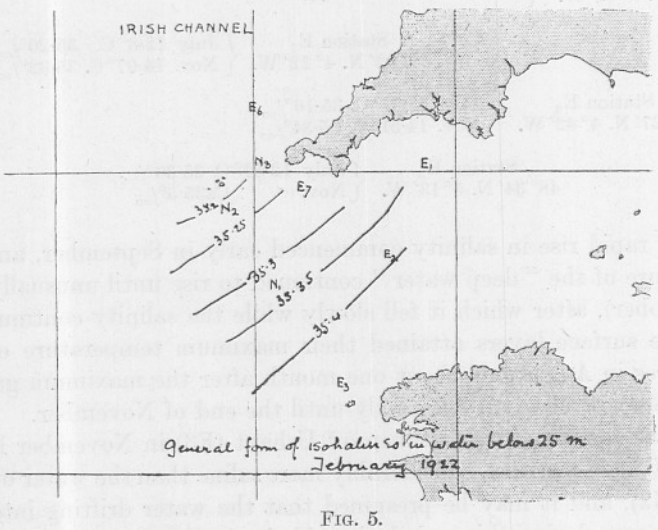


Fig. 5.

year. The latter part of June and early July were marked by boisterous weather, and vertical mixing took place. This can be seen on comparing the diagram of vertical distribution for July 11 with those for June 6 and August 3. This condition is further reflected in the curves of temperature at 5 metres and below 25 metres, the rate of temperature increase

of the warmer 5-metre layer being checked by mixing with the colder water below. The deep water in its turn suffered a slight rise in rate of temperature increase.

Considering the salinity, the fall in June, February, and March appears due to a southerly drift from the southern part of the Irish Channel, which ceased in May. The general arrangement of the isohalines (Figs. 4 and 5) in the deep water, as found during the February and March cruises, illustrates this point.

The data for the period early May to the end of July (see Table II) indicate water-masses of relatively high salinity, which had entered the Channel early in the year, moving westward particularly off the English coast. Gehrke* has shown on theoretical grounds that more water enters the English Channel from the westward than escapes into the North Sea, and that a portion must, therefore, turn back and escape in a north-westerly direction.

TABLE II.

Year 1922. Average Temperature and Salinity of Water below 25 meters.

Station N_2 49° 46′ N. 6° 21′ W.	Feb.	10·25° C.	35·21‰
	Mar.	9·39° C.	35·18‰
	May	10·34° C.	35·21‰
	July	12·34° C.	35·24‰
	Nov.	11·67° C.	35·25‰
Station N_1 49° 14′ N. 5° 51′ W.	Feb.	—	—
	Mar.	9·82° C.	35·25‰
	May	10·56° C.	35·34‰
	July	10·9° C.	35·29‰
	Nov.	11·77° C.	35·28‰
Station E_1 50° 02′ N. 4° 22′ W.	Feb.	10·51° C.	35·33‰
	Mar.	9·62° C.	35·27‰
	May	10·11° C.	35·37‰
	July	11·99° C.	35·39‰
	Nov.	12·07° C.	35·28‰
Station E_2 49° 27′ N. 4° 42′ W.	Feb.	10·62° C.	35·42‰
	Mar.	9·90° C.	35·39‰
	May	10·62° C.	35·34‰
	July	12·70° C.	35·36‰
	Nov.	12·30° C.	35·29‰
Station E_3 48° 34′ N. 5° 13′ W.	Feb.	10·80° C.	35·44‰
	Mar.	10·19° C.	35·37‰
	May	11·03° C.	35·30‰
	July	11·70° C.	35·34‰
	Nov.	12·57° C.	35·32‰

The water at 5 metres reached its maximum temperature early in August, as in the previous year, and after the middle of October cooled rapidly. The deep water reached its maximum temperature some five

* Gehrke. The mean velocity of the Atlantic currents running north of Scotland and through the English Channel. Publ. de Circonstance, No. 50. Copenhagen. Also Matthews. *Fisheries.* Ireland Sci. Invest., 1913, IV.

TABLE III.

	1921						1922											
	May 27	Aug. 12	Aug. 15	Oct. 21	Nov. 9	Dec. 21	Jan. 11	Feb. 6	Feb. 11	Mar. 15	Mar. 29	May 22	June 6	July 11	Aug. 3	Sept. 22	Oct. 11	Nov. 9	Dec. 18
L_1 surface	13·9	16·2	15·9	16·0	11·59	10·62	10·01	8·2	7·8	8·5	8·0	14·4	13·8	13·8					
														14·5	14·60	14·6	13·8	10·3	9·7
bottom	12·47													14·21	13·88				
L_2 surface	12·78	15·4	15·6	15·98	13·01	11·41	10·10	8·8	7·93	8·8	8·4	13·0	13·3	14·1					
														13·9	13·8	14·5	14·1	10·5	9·9
bottom	11·67													12·97	13·68	14·4			
L_3 surface	12·22	15·3	15·7	15·99	14·04	11·78	10·27	8·9	8·3	8·9	8·6	12·9	12·6	14·1	14·3	14·6	14·1	11·2	10·2
bottom	11·35													12·40	12·93				
L_4 surface	11·75	15·5	15·7	15·95	14·29	12·34	10·31	9·2	8·9	9·2	8·7	12·9	12·8	15·3					
														14·2	14·22	14·4	14·25	—	10·5
bottom	10·98													12·32	12·80				
L_5 surface	12·04	15·3	15·5	15·86	14·39	12·64	11·11	9·5	9·2	9·3	8·9	12·3	12·8	14·0	14·35	14·4	14·3	11·8	10·9
bottom	10·97													12·10	12·66	13·33			
L_6 surface	13·30	15·5	15·4	15·74	14·29	12·79	11·17	9·9	9·8	9·5	9·1	12·6	12·8	14·1	14·55	14·6	14·2	12·1	10·9
bottom	10·79													11·91	12·33	14·24			
			14·6																
			16·21	15·55	14·30														
E^1 surface	13·5	16·13	15·7	15·63	14·96	12·94	11·23	9·9	9·9	9·6	9·7	12·8	13·95	12·8	15·0	14·3	14·2	12·2	10·9
5 m.	13·49	16·17	(15·6)	15·51	15·00	13·13	11·29	10·51		9·64		12·70	13·89	12·36	14·58	14·21	14·10	12·19	
below 25 m.	10·79	13·29	13·33	15·39	14·97	13·13	11·34	10·51		9·62		10·11	10·32	11·99	12·38	14·17	14·01	12·07	
Ground temp. on Hoe 1ft. below surface*	15½	16½	16½	13	10½	6½	6	5½	5½	6½	7	14½	15½	15½	15½	14	11½	7½	

Temperatures in degrees Centigrade. * From curve of monthly means.

weeks later in September, which was a month earlier than the maximum in the previous year. Since July the salinity had been falling. A rapid fall in temperature occurred throughout the whole water-mass after the middle of October, whereas in 1921 a rapid fall did not occur until the middle of November.

The data obtained between July and November (see Table II) are insufficient to give an indication whence the increasingly warm water

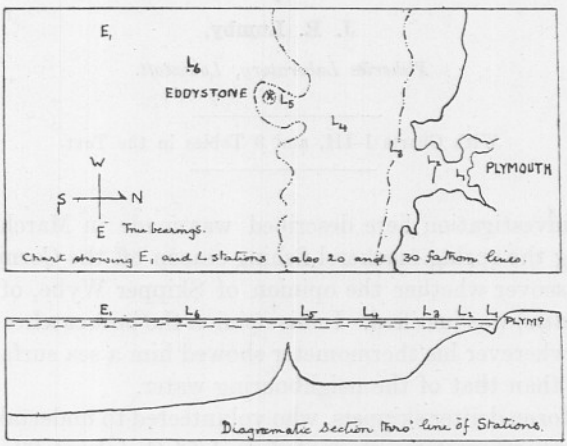


FIG. 6.

below 25 metres came, after the surface water had reached its maximum temperature in August.

Table III shows the conditions inshore along the line of stations between Plymouth Hoe and E1, the positions of which are given on the map (Fig. 6) together with the twenty and thirty-fathom line.

Two noteworthy features are apparent. The maximum temperature of the sea lags behind the temperature of the ground. As the shore is approached both greater and more rapid variations in temperature are experienced.

The Relation between Catches of Mackerel and the Surface Temperature *in situ*.

By

J. R. Lumby,

Fisheries Laboratory, Lowestoft.

With Charts I–III, and 3 Tables in the Text.

THE short investigation here described was made in March and April, 1922, during the spring mackerel fishing season off the Cornish coast, in order to discover whether the opinion of Skipper Wylie, of Lowestoft, (drifter, *Realize*) was justified. In his opinion the best catches of mackerel were made wherever his thermometer showed him a sea surface temperature higher than that of the neighbouring water.

About a dozen drifter skippers, who volunteered to undertake the work, were given thermometers, graduated in 1/5° C. (about 20 graduations per cm.) and forms upon which to record their observations, and were shown how to take a surface sample and read its temperature. These thermometers were not very suitable, since the range was too great, and therefore the scale too small. They also suffered from the defect that the mercury thread easily become broken, and if the detached portion ran down into the bulb at the top of the tube, it was difficult to ensure that all the mercury came out again, and that the thread made a proper joint.

The forms used (p. 241) were based upon the log books used during the investigations on pelagic fishes from 1895 to 1911* (Russell, 1915). It was hoped that sufficient data would be collected in the course of a month, but, although the experiment was extended into April, only 32 records are available, covering the period 9th March–19th April.

These records are tabulated in Table 1. In those cases where the temperatures at the times of shooting and hauling differed, both the values are given, but their mean has been used in computing averages.

The first and second columns refer to the position of hauls shown on the charts. The hauls between the 9th and 15th March have been plotted on Chart I, between 19th and 30th March on Chart II, and between 4th and 19th April on Chart III.

* Ministry of Agriculture and Fisheries. Fishery Invest. Ser. 11, Vol. III, No. 1, 1915.

An inspection of the charts seems to show a movement of the fishing away from the Bristol Channel and Wolf Grounds after the middle of March, after which date nearly all the records are from grounds west of

MACKEREL AND TEMPERATURE, 1922.

TABLE I.

Chart.	Letter.	Date.	°C. Temp.	Wind.		Sea.	Weather.	Water Colour.	Catch.	Nets.	Catch per Net.
I	A	9.3.22	10	N.	3	3	b.c.	Lt. gn.	1,200	200	6·0
	B	,,	9·8	N.N.W.	2	3	b.c.	Lt. gn.	300	220	1·4
	C	,,	9	N.N.W.	3	3	b.c.	Clear lt. gn.	600	90	6·7
	D	10.3.22	9·8 9·7	N.N.E.	4	4	b.c.	Clear lt. gn.	200	220	·9
	E	9.3.22	—	N.	2	3	b.c.p.	—	150	207	·7
	F	10.3.22	—	N.E.	4	4	c.	—	2,500	207	12·1
	G	11.3.22	10·1 10·0	N.N.E.	2–3	2–3	b.c.	Green	200	207	1·0
	H	,,	9	N.×E.	3	3	b.c.	Clear lt. gn.	500	200	2·5
	J	12.3.22	9·8	E.N.E.	3	3	b.	Green	800	207	3·9
	K	13.3.22	9	E N.E.	3	3	b.c.	Green	300	200	1·5
	L	14.3.22	9·8 9·6	E.S.E.	3	3	b.c.	Lt. gn.	2,000	200	10·0
	M	15.3.22	10·0	E.S.E.	4	4	b.c.m.	Thick lt. gn.	7,000	200	35·0
	N	,,	9·8	E.S.E.	4	4	c.	Clear lt. gn.	1,500	90	16·7
II	A	19.3.22	10·0	N.E.	3	3	b.c.m.	Dk. gn.	10,000	200	50·0
	B	,,	10·0 9·8	N.E.×N.	3	3	d.	Rather thick med. dk. gn.	3,000	200	15·0
	C	20.3.22	9·6	N.E.×N.	4	4	p.s.	Thick med. dk.	4,000	200	20·0
	D	23.3.22	8·4	N.N.E.	3	4	c.	Clear lt. gn.	4,000	90	44·4
	E	24.3.22	10·5	N.W.	3	3	b.c.q.	Thick lt. gn.	600	220	2·7
	F	26.3.22	9·7	N.W.	4–5	4–5	b.c.q.	—	1,000	207	4·8
	G	28.3.22	9·5	N.E.×E.	3	4	b.c.q.	—	2,000	207	9·7
	H	,,	8·4	N.E.×E.	3	4	b.c.	Clear lt. gn.	1,200	90	13·3
	J	29.3.22	10·2	S.S.E.	2	2	b.c.	Clear lt. gn.	800	90	8·9
	K	30.3.22	9·4	S.S.W.	2	2	b.c.	Med. dk.	Nil	90	—
	L	,,	9·8	N.N.W.	4	4	c.q.	Lt. gn.	1,800	210	8·6
III	A	4.4.22	9·4	W.N.W.	3	4	b.	Clear slate	1,400	90	15·6
	B	,,	10·0 10·3	W.S.W.	3	3	b.c.	Lt. gn.	2,000	209	9·6
	C	5.4.22	10·5 10·3	W.S.W.	2	2	b.c.	Lt. gn.	3,000	209	14·4
	D	,,	9·6	W.N.W.	3	2	b.c.	Clear lt. gn.	2,600	90	28·9
	E	11.4.22	10·0	S.S.W.	2	2	c.	Lt. gn.	150	90	1·7
	F	13.4.22	9·2	E.×N.	2	4	c.p.	Clear lt. gn.	450	90	5·0
	G	18.4.22	10·0	N.	2	2	b.	Clear lt. gn.	Nil	90	—
	H	19.4.22	10·0	N.×E.	2	2	b	Clear	Not stated	90	—

the Scilly Islands. This is in consonance with the results of the Log Book investigations above referred to.

The times at which boats were accustomed to shoot and haul were all approximately the same, so that it is unnecessary to consider diurnal

variation in the discussion of the temperatures. The routine followed was to shoot about an hour before dark, viz. 5 to 6 p.m., and to haul about midnight.

TABLE II.

"SEVEN STONES."

Date.	Time.	Temp. °C.		Salinity °/₀₀.	Wind.
		Sea.	Air.		
1922					
March 1st	4 p.m.	9·8	6·7	35·17	—
5th	5.30 p.m.	10·2	11·7	·24	—
9th	9 a.m.	9·4	11·7	·30	N.N.W.
13th	1.30 p.m.	9·7	9·4	·23	E.
17th	5 p.m.	9·8	9·4	·28	S.E.
21st	10 a.m.	9·4	—	·22	—
25th	noon	9·3	7·8	·23	N.N.W.
29th	10 a.m.	9·5	7·8	·21	S.E.
April 1st	2 p.m.	9·1	7·2	·23	E.N.E.
5th	9 a.m.	9·6	—	·35	S.W.
9th	noon	9·7	10·0	·37	N.
13th	4 p.m.	10·3	8·3	·26	S.E.
17th	5 p.m.	9·7	7·8	·24	N.E.
21st	8.30 a.m.	9·8	10·0	·26	N.
25th	noon	9·6	10·0	·28	N.
29th	3 p.m.	9·3	6·7	·24	—

TABLE III.

MEAN MONTHLY VALUES AT "SEVEN STONES."

1922.	Temp. °C.	Anomaly.	Salinity. °/₀₀.	Anomaly.
January	11·1	+1·0	35·34	+·08
February	10·0	+0·5	·30	+·06
March	9·6	+0·5	·24	+·01
April	9·7	+0·1	·27	+·04
May	11·4	+0·7	·23	+·01

Taking the records as a whole, the average temperature corresponding to catches of 10 and over per net is 9·6° C., and that corresponding to catches of less than 10 is 9·7° C. It is of interest to note here that the mean

monthly temperatures at the "Seven Stones" for March and April are 9·6 and 9·7° C. respectively (Table III). As regards the average figures from the records, this difference of 1/10° C. is scarcely significant, taking into consideration the liability of the observations to error: for example, for two adjacent hauls, Chart I, A and C, on the same date, temperatures of 10° and 9° are recorded.

Apparently, then, only very small temperature changes seem to have occurred over the whole area. The "Seven Stones" observations (Table II) were taken at varying times during the day, yet, there, the

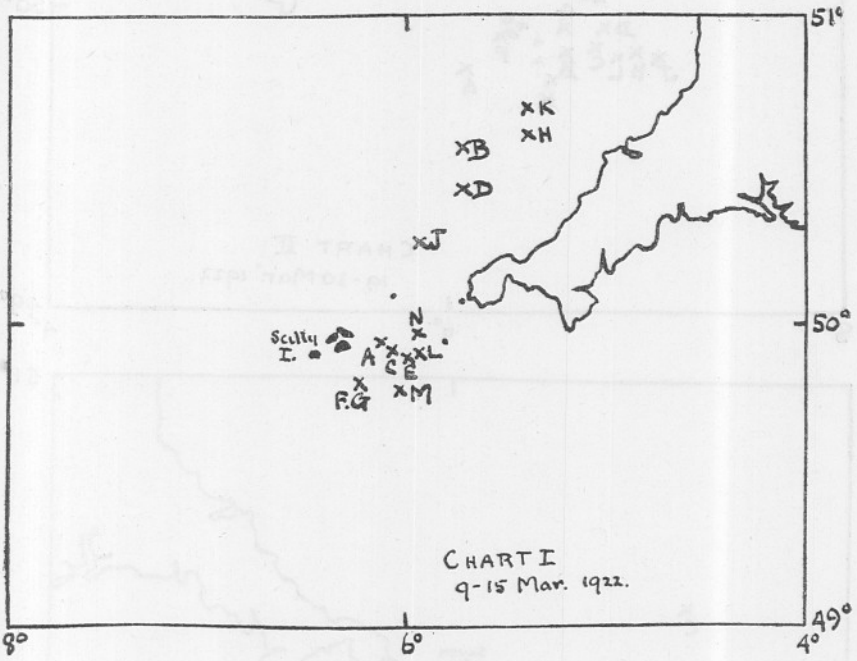
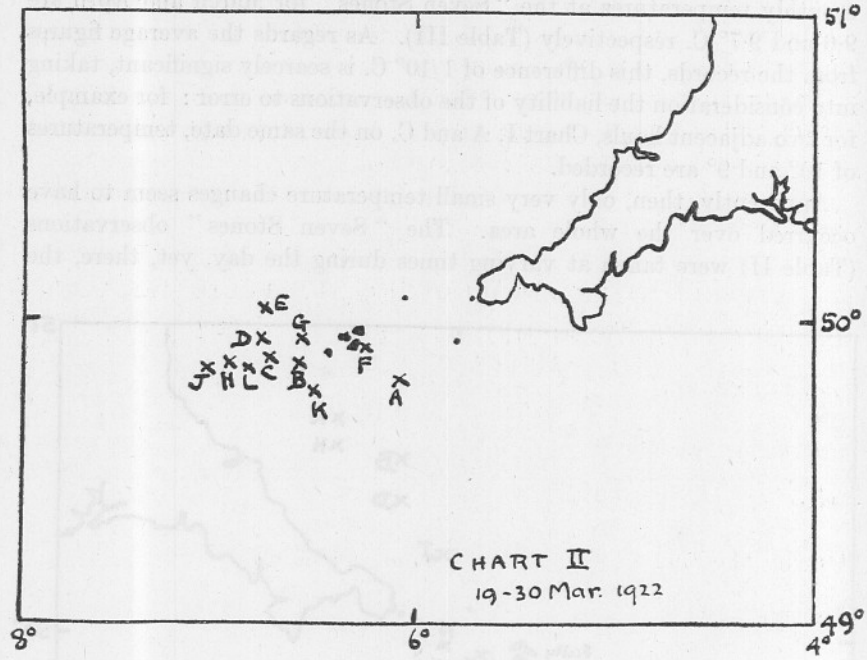


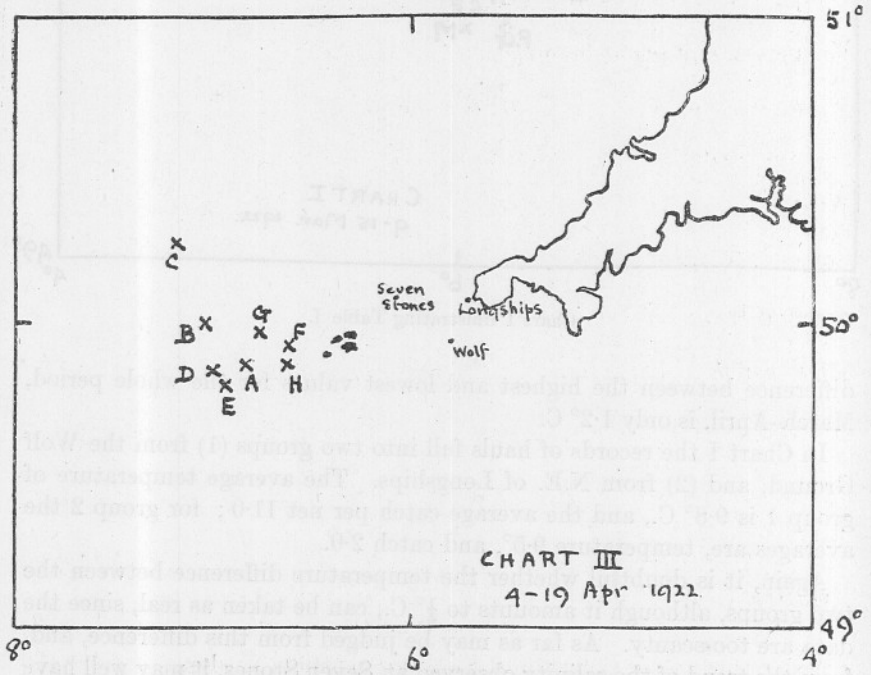
Chart I illustrating Table I.

difference between the highest and lowest values for the whole period, March–April, is only 1·2° C.

In Chart I the records of hauls fall into two groups (1) from the Wolf Ground, and (2) from N.E. of Longships. The average temperature of group 1 is 9·8° C., and the average catch per net 11·0; for group 2 the averages are, temperature 9·5°, and catch 2·0.

Again, it is doubtful whether the temperature difference between the two groups, although it amounts to $\frac{1}{4}$° C., can be taken as real, since the data are too scanty. As far as may be judged from this difference, and from the trend of the salinity observed at Seven Stones, it may well have





Charts II and III illustrating Table I.

been the case that colder water was driven under the influence of the strong north-easterly winds prevailing then from the Bristol Channel down the north coast of Cornwall.

To sum up, it is clear that the data are insufficient to use as a basis for reliable differentiation, but generally it appears that high temperatures are not necessarily related to good catches.

The help and advice of the Director and Staff of the Plymouth Laboratory are gratefully acknowledged.

MINISTRY OF AGRICULTURE AND FISHERIES.

MACKEREL FISHERY INVESTIGATIONS, 1922.

Name of Vessel .....

Port Letters and No. .....

Date .....

Time of Shooting ..... Time of Hauling .....

Position .....

Temperature of sea at shooting .....

Temperature of sea at hauling .....

Wind direction ..... Force .....

Sea disturbance .....

Weather .....

Colour of Water .....

Smell of Water .....

Kind of Fish .....

Number of Nets .....

Mesh .....

Total Catch .....

Remarks .....

(Signature).....

Please return to the Collector of Fishery Statistics, Newlyn.

To take the temperature of the sea.

It is requested that a uniform method may be adopted. A suitable clean bucket is hove from a position of the ship well clear of all waste discharges. The bucket having been well rinsed by two or three successive casts, in order to clean it and bring it to sea temperature, a final sample is drawn and the temperature taken. The thermometer having been inspected, is immersed and used to stir the sample until the reading is constant, To read the height of the mercury column, the thermometer, with the bulb still immersed, is held in such a position that it is perpendicular to the direction of sight. The temperature should be read to the nearest graduation mark. The graduations between the whole numbers are ·2, ·4, ·6 and ·8. The reading is noted *at once* to avoid errors due to forgetfulness.

Scale of Wind.

1. Calm.	3. Moderate breeze.	5. Gale.
2. Light breeze.	4. Strong wind.	6. Storm.

Scale of Sea Disturbance.

1. Calm.	3. Moderate.	5. Very rough.
2. Slight.	4. Rough.	6. Tremendous sea.

Scale of weather.

b. Blue sky.	o. Overcast.
b.c. Partly clouded.	p. Passing showers.
c. Nearly all clouded.	r. Steady rain.
d. Drizzle.	s. Snow.
f. Fog.	rs. Sleet.
f. Very foggy.	t. Thunder
h. Hail.	u. Threatening.
l. Lightning.	w. Dew.
m. Mist.	x. Frost.

Scale of Colour of Water.

Very dark.
Medium dark.
Light green.
Yellow-green.
Mention if thick or clear.

Scale of Smell.

No smell.
Little smell.
Stinking.

Note upon an Association between Spider-Crab and Sea-Anemone.

By

David Landsborough Thomson, M.A.

It was observed during the summer of 1920 that specimens of the Long-legged Spider-crab, *Stenorhynchus phalangium* Penn., which happened to be in the crowded tanks of the Roscoff Laboratory, were always to be found in the neighbourhood of specimens of *Anemonia sulcata* Penn. (*Anthea cereus* Ellis). That this was not merely accidental was shown when crabs, removed to a distance of over three feet, returned time after time to an *Anemonia*, passing on the way anemones of various species, as well as all manner of objects which might conceivably afford shelter. Of fifteen healthy crabs of this species observed during the past three summers, every one showed this tendency in greater or less degree. At least two of these crabs were found clinging to anemones of this species on the shore, between tide marks; but the subsequent behaviour of crabs dredged from deeper water was in no way different.

Usually the crab takes up its position close to the column of the anemone, so as to be more or less concealed by the tentacles, only the rostrum and the first pair of walking legs being visible from above, whilst the legs of the fourth pair may reach backwards to grasp the anemone. But at times, and especially when disturbed, the crab climbs backwards right on to the crown of the anemone; and one specimen, a female bearing eggs, repeatedly worked its way right under the base of the anemone, so that only the tip of the rostrum and the limbs could be seen. The anemone makes no attempt to seize the crab, but if the crab dies its body is soon lifted up and devoured. It is clear that the crab must be well protected by the anemone, which does not retract its tentacles when disturbed. At night, when the tentacles of *Anemonia* usually hang limp and inactive, the crab often ventures out from its sheltered position.

If a scrap of flesh be dropped into a basin containing an *Anemonia* and a *Stenorhynchus*, the crab soon becomes aware of it, and begins to search energetically. As soon as the morsel of food is found, it is dragged back into the friendly shelter of the anemone; but in an instant one of the restless tentacles has discovered it, and it is snatched from the crab's uncertain grasp and swallowed by the anemone, while the defrauded

owner searches the neighbourhood with a comical suggestion of bewilderment. A day or so later the undigested remains are ejected by the anemone in the form of a white film, which soon swarms with algæ and infusorians. Once again the crab begins to search, but it may be a considerable time before it finds and devours these remains. It may frequently be observed, when the crab is in its usual position, that a single tentacle of the anemone hangs loosely over the rostrum and in front of the mouth. The benefit to the anemone is thus no less plain than the benefit to the crab, in this quaint partnership, which may, perhaps, be regarded as an early stage in the establishment of a true commensalism.

The Larval Stages of *Processa canaliculata* Leach *

By

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With Figures 1–9 in the Text.

THE material upon which the following account of the development of *P. canaliculata* is based was mainly obtained in 1902 when working in the Laboratory at Plymouth. The larvæ were first noticed, and their identity suspected, in April of that year, and identification was made certain by keeping the larvæ in the "mysis" stage until they moulted into the post-larval form, some individuals being kept also through several subsequent moults. The intermediate stages were all taken from the plankton, since I was unable to hatch the larvæ from the egg. The only egg-bearing female seen at that time was taken on the Eddystone Ground on April 29, and her eggs were so far advanced that, although she was unfortunately killed, a few larvæ escaped from the eggs and made it possible to obtain some idea of the structure of the first zoæa.

During a short stay in Plymouth during April, 1922, I was able not only to pick out a few more specimens from the plankton then brought in, but also, by working through a large number of preserved plankton samples, to obtain a considerable amount of additional material, mainly of later stages. A few specimens have also been found in samples of plankton from the North Sea preserved at the Fisheries Laboratory at Lowestoft, for the loan of which I am indebted to Mr. A. C. Hardy. But the larvæ of this species are much rarer in the North Sea than in the neighbourhood of Plymouth, where they are quite common.

Several females with eggs were brought in during my visit in 1922, but unfortunately the eggs were in all cases in early stages and the attempt to keep them till they hatched failed. I was, however, fortunate in finding in the plankton one zoæa in the first stage, so that the series from hatching to the adult is complete.

The breeding period evidently begins very early. Egg-bearing females have been taken at Plymouth in February, and advanced larvæ occur

* Leach's name was published on July 1, 1815, in Part IV of his Malacostraca Podophthalmata Britanniæ. *Processa canaliculata* must, therefore, be used in place of *Nika edulis* Risso, 1816.

in the plankton early in April, and continue throughout the summer. Advanced larvæ only are taken in September. Risso states (1816) that the eggs are laid several times in the year, and so extended a breeding period points to the production of several broods.

P. canaliculata is a species of extraordinarily wide distribution and has a vertical range from between tide marks to 326 fathoms. According to Kemp it is found all round the English and Scottish coasts, but appears to be mainly a southern form.

My own experience of it is very limited, but Dr. J. H. Orton has been kind enough to give me information as to its occurrence in the Plymouth area. It is found in Plymouth Sound occasionally in very small numbers, and has even been taken on the shore, but it is not uncommon in the deeper water of the Rame Head and Eddystone Grounds in 20–30 fathoms, either on mud or on sand.

Specimens kept in aquaria and provided with stones were always found quiescent during the day, wedged in between the stones, so that it is possible that it may be common on rocky grounds where, however, its presence would with difficulty be ascertained. It shows no inclination to burrow in sand.

The colour changes of this species are rather striking, and Jourdain (1878) has described experiments on this change of colour. In sunlight the animal was found to be transparent, slightly tinged with brown, but to become red in the dark. Light had, therefore, the effect of causing contraction of the pigment in the chromatophores.

Two specimens were kept under observation in 1902. These were both of a dirty white colour when brought up in the trawl, but both, in a subdued light, became later of a flesh-pink colour, which was retained, except when in a strong light. One of the specimens which was kept in the dark for some hours became quite red, but when taken out and placed in strong light became white in nine minutes, the antennæ retaining the pink colour longest.

In April, 1922, I had the opportunity of watching several specimens. Some of these were kept on shelly sand, and these varied little in colour, being of a pale rose-red during the day and a little redder at night.

On the other hand, a specimen brought in from the Sound, and kept among rocks, was of a greenish colour when taken, and remained so for four days. It then became a brilliant red at night, reverting to green in the daytime. From that time till I left Plymouth the same change occurred regularly, the brilliant red of its nocturnal colouring being very striking. Risso describes the colour as "rouge incarnat," but with yellow spots; while Cuvier also figured it (1829) a vivid red. Dr. Orton informs me that the colour is always red when the animal is brought up

from deep water. This is probably the normal colour under natural conditions, and the changes observed in the Laboratory are merely due to abnormal lighting.

So far as I am aware the only published reference to the larva of Processa is that of Czerniavsky (1884), who mentions a larva of 6 mm. in length, but without giving much information concerning it. He seems to have had before him a specimen either in the last larval or first post-larval state.

As will be seen from the following account, the zoæae of Processa are so like those of Pandalus and Spirontocaris that the recognition of the early stages is by no means easy, and the development further resembles that of Pandalus in the number of moults passed through, and the gradual attainment of the adult form. Sars has distinguished eight or nine larval stages in the development of *Pandalus borealis*, and the same number is found in *Pandalina brevirostris*; while in the Crangonidæ, and also commonly in the Palæmonidæ there are only five stages corresponding to the same number of moults. In Processa I have found the separation of the larvæ into distinct stages of development a matter of extreme difficulty. When working through my original material it seemed that eight stages could be distinguished, though only by small differences; but examination of increased material has shown that individual variation is so great that the distinctions between the stages, both in respect of size and also of development of appendages, almost disappear. I now, however, recognise nine stages which will be defined below, but it must be admitted that, after Stage III, the series is practically continuous. It does not necessarily follow, and I also think it improbable, that any one individual will pass through each of these stages. Sollaud (1912) has stated that the number of moults in the development of Palæmonetes varies to some extent with the conditions of life, and I have myself found that Palæmonetes larvæ kept under the rather adverse conditions of aquarium culture may moult repeatedly without material structural changes. It is probable that in Processa and also in Pandalus some of the " stages " may be omitted by more vigorous individuals, while they may be even more numerous in others. For example, on the one hand Stage VIII may certainly moult direct to the post-larval condition and, on the other hand, I have included in Stage V a number of larvæ which are not of equal age, indicating that this stage may represent more than one moult.

In Caridean development the first two moults seem invariably to produce larvæ of exactly the same general structure, so that Stages II and III are precisely comparable throughout, while from this stage onwards development may proceed as in Processa by progressive small changes. It is only in certain groups such as the Crangonidæ that larval

development is compressed within five stages, separated by important structural differences.

In *Pandalina brevirostris* the development from hatching to the post-larval state takes, under laboratory conditions, about two months,* which is considerably longer than that of Leander, in which a moult takes place at intervals of about eight days, and development is complete in about four weeks (Mortensen, 1897). It seems likely, therefore, that moults occur in Pandalus and Processa at about the same intervals, so that the duration of larval life is increased. The difficulty of keeping these larvæ alive for any length of time makes it impossible to attain to any certainty in a matter of this kind.

I am indebted to Miss Lebour for records of the moults of a specimen reared by her in a plunger jar at Plymouth. This specimen was in Stage VIII when first put in the jar and moulted as follows :—

To Stage IX	April 3, 1922
To 1st Post-larval . . .	April 12 ,,
To 2nd ,, . . .	April 22 ,,
To 3rd ,, . . .	May 1 ,,
To 4th ,, . . .	May 8 ,,

STAGE I. Length, 1·9 to 2·2 mm.

The general form closely resembles that of *Pandalina brevirostris*, but the rostrum is apparently absent and the fifth abdominal segment bears in this, and in all succeeding stages, a pair of small dorsal spines. The presence of these spines suffices to distinguish the larva at any stage from that of Pandalina, but similar spines have been seen in larvæ apparently belonging to some species of Hippolytidæ (e.g. *Spirontocaris cranchii*). A pair of spines is present on this segment in late larvæ of *Pandalus bonnieri*, and (according to Sars) in *P. montagui*, but they are absent in the first zoæa of the latter. *P. borealis* resembles Processa in having them at all stages.

The ventral margin of the shell ends anteriorly in a strong spine behind which there are two small denticles. These denticles increase in number in later stages and are retained until the post-larval stage.

The telson is triangular and much less deeply cleft than in Pandalus. The outermost seta is inserted nearly half-way up the side, and both it and the next seta are ciliated on the inner side only.

The first antenna is long and slender, the first joint bearing a long ciliated seta, and the second a ciliated seta and three æsthetes.

The second antenna has a scale bearing two setæ on the outer side as

* Larvæ of the species were reared from hatching to the post-larval state in 1903 in a "plunger jar" in the Plymouth Laboratory.

in Pandalus and Hippolyte, and ten inner and terminal setæ (see Fig. 2, A). The outer setæ are much longer than in *Hippolyte varians*. There is no trace of segmentation of the end of the scale, a striking difference between this species and the larvæ of both Pandalidæ and Hippolytidæ so far as is known. The endopodite is a tapering spine

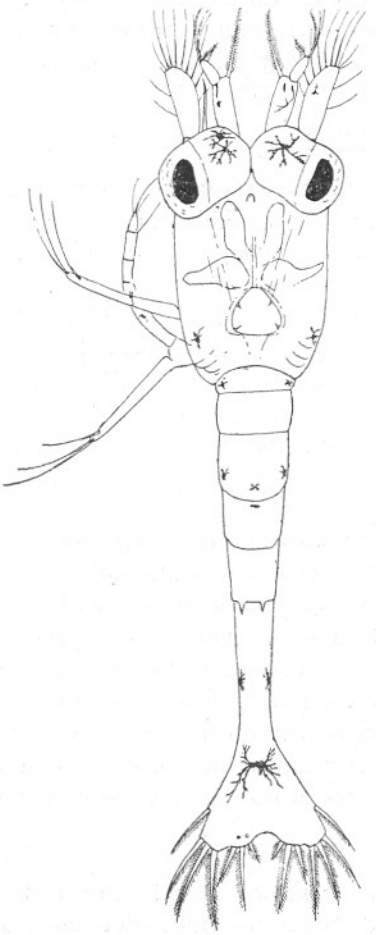


FIG. 1.—Stage I, showing the arrangement of the Chromatophores.

scarcely more than half the length of the scale. In Pandalus this branch bears two setæ.

The three pairs of maxillipedes are present as biramous swimming legs, while the rudiments of the first two pairs of pereiopods are visible. The exopodites of the maxillipedes bear respectively 4, 5, 5 setæ.

As has been said above, I have seen larvæ which were liberated from the

egg on killing of the parent. Though larvæ in later stages have been found in abundance in the plankton, I have only on one occasion recognised a larva in the first stage. This one was taken on 22.4.22, and measured 1·95 mm. The chromatophores are yellow or yellow and red, and their distribution is shown in Fig. 1.

The zoæa of *Spirontocaris cranchii*, which closely resembles that of Processa, may be recognised by its minute rostrum and jointed antennal scale. It is also much more highly coloured, with very numerous large chromatophores.

Stage II. Length 1·85 to 2·9 mm.

I have seen several larvæ of this stage, the majority measuring about 2·3 mm., but a single individual of 1·85 mm. shows that there may be a great range in size. S. Kemp (1906) has drawn attention to the exceptional variation in size of the adult.

The rostrum is now present, though very small, and a pair of small supra-ocular spines have appeared. Just behind the rostrum is a small, rounded knob, and in later stages a second similar knob appears on the carapace towards its posterior end.*

The eyes are stalked, and the telson has gained an additional median pair of setæ. The second seta of the telson is ciliated on both sides.

The two pairs of antennæ scarcely differ from those of the first zoæa, but I should draw attention here to a small lobe which, in this and all later stages, is borne at the end of the stem. This lobe carries four small, feathered setæ with swollen bases similar to the sensory setæ which appear later at the base of the antennule in the region of the otocyst. The interest of this, which I shall call the "antennular lobe," lies in the fact that a precisely similar structure is found in the larvæ of most, if not all, Caridea, and is retained in many cases in the adult (e.g. Leander), while a structure which is obviously homologous occurs also in adult Euphausiacea (e.g. Nyctiphanes) and in most Mysidæ (e.g. Neomysis).

The mandibles (Fig. 2, C) show distinct differentiation into molar and cutting parts, and are slightly asymmetrical as regards the spines borne by them.

The first maxillæ are of the usual form, consisting of two basal lobes, the proximal one armed with five long, curved spines and the distal with a number of short, thick spines in two rows (Fig. 2, B). The palp is distinctly two-jointed, the proximal joint with two and the distal with three spinous setæ. The second basal lobe bears a seta on its outer side.

* The anterior knob corresponds to the "dorsal organ" referred to by Hansen in his "Studies on Arthropoda," 1921.

It is possible that this seta, which is also found in Hippolyte (Sars) and in some Brachyura, may represent the setiferous lobe (exopodite ?) of the first maxilla of Sergestidæ. It is not found in Leander, the Crangonidæ or Pandalidæ.

The second maxilla has a large palp or endopodite with three inner lobes (Fig. 4, A). The basal part of the appendage bears four distinct lobes, and apparently consists of two joints, each bearing two lobes or endites. There is, in most Caridea, a distinct division between the

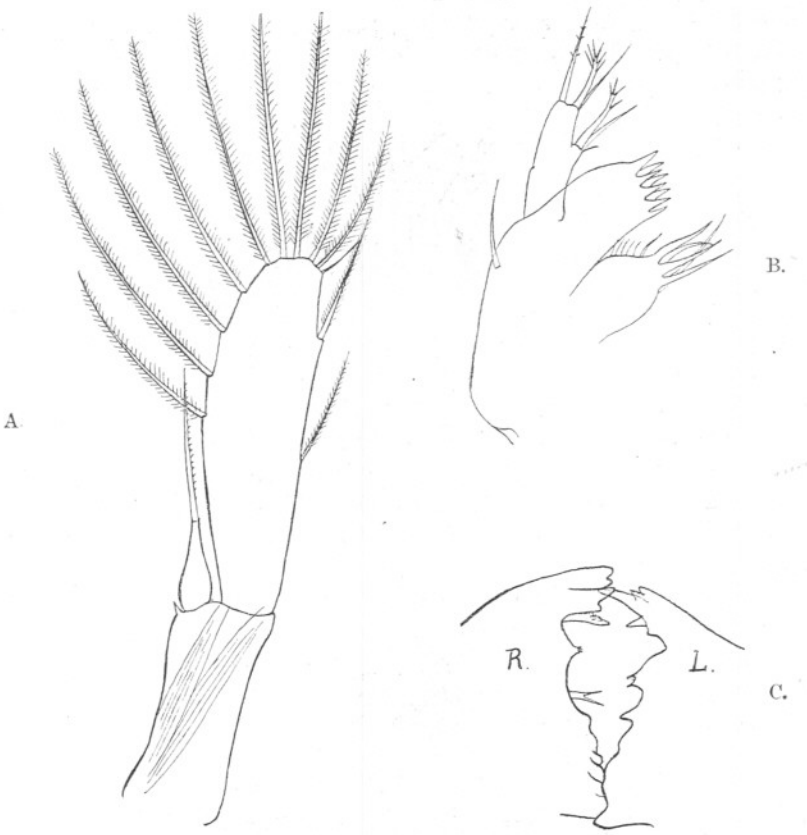


FIG. 2.—Stage II.

A. 2nd Antenna.
B. 1st Maxilla.
C. Mandible.

regions bearing the basal and distal pairs of lobes, and it is quite clear that the palp and scaphognathite are endopodite and exopodite respectively springing from the second joint; but it is generally possible to distinguish a line of division running between the two basal

lobes to an indentation of the outer edge, giving the appearance of three joints. On the other hand, this apparent line of division bears no relation to the muscles of the limb, and I am of opinion that it does not really indicate a three-jointed stem.

The first pair of pereiopods is developed as a swimming limb with a five-jointed endopodite nearly equal in length to the exopodite. The ischio-meral joint in this and in the maxillipedes is indistinct at this stage. The exopodites bear 5, 5, 6, 6 setæ respectively. The last four pairs of pereiopods are visible as buds, those of the second pair being bilobed and larger than the others.

The first maxillipede bears a minute rudiment of the epipodite, but there is no trace of gills.

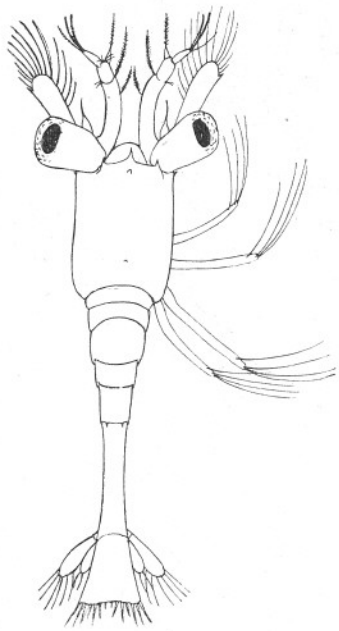


Fig. 3.—Stage III.

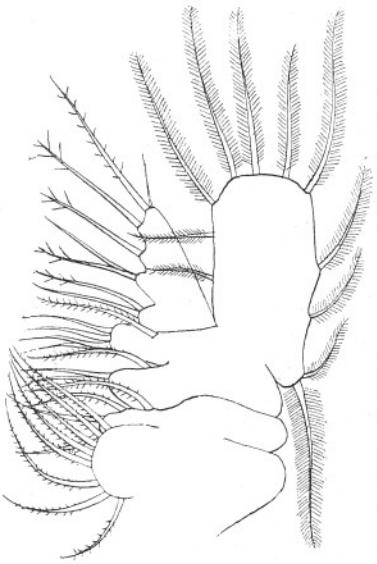
Stage III. Length 2·53 to 2·65 mm.

The general form of the body in this and succeeding stages remains the same, the carapace broad and parallel-sided, with a minute rostrum not reaching to the end of the frontal lobe, and a pair of supra-ocular spines. The telson is still triangular in shape, but somewhat more elongated in proportion to its width, and bears fourteen terminal spines, the outermost spine of Stage II having been lost.

The first antenna has a two-jointed stem which is greatly curved and

shows a faint trace of separation of the first joint into two. This joint bears two inner setæ only. The inner branch is in the form of a minute knob bearing a seta, and the outer branch bears one ciliated seta and three æsthetes. These æsthetes are easily broken off, but it will probably be found that three is the normal number for all Caridea in this and earlier stages.

The second antenna differs from preceding stages in the reduction or loss of the two outer setæ on the scale, and the presence of an outer terminal spine. The scale is markedly wider distally and retains this character in later stages. The flagellum has still the form of a small knob terminating in a spine.



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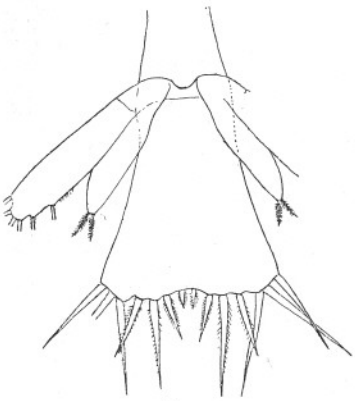


B.

FIG. 4.—Stage III.
A. 2nd maxilla.
B. Telson and uropods from below.

The mouth parts show no important change, except that the seta which is present on the outer side of the second basal lobe of the first maxilla appears to be lost.

The first and second pereiopods are now biramous swimming limbs with long five-jointed endopodites.

The first maxillipede has a small epipodite, but I have not been able to see any trace of gills.

The pleopods are not visible, but the uropods are developed, the outer branch with six setæ and the inner with two small terminal setæ (Fig. 4, B). There is no ventral spine at the end of the sixth abdominal segment.

Stage IV. Length 2·8 mm.

The chief differences between this and Stage III are :—

1. The first antenna has two additional inner setæ on the first joint.

2. The flagellum of the second antenna has lost its terminal spine and is now a short rod without setæ.

3. The epipodite of the first maxillipede is larger.

4. The third pereiopod is now fully developed.

5. There are rudiments of three pairs of pleurobranchs corresponding to the first three pereiopods (Fig. 5).

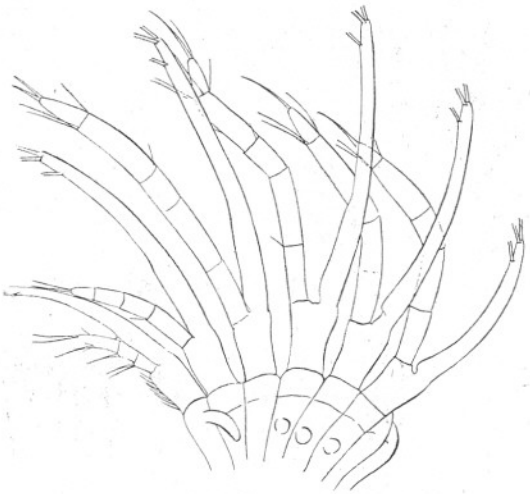


Fig 5.—Stage IV, thoracic appendages, showing rudiments of pleurobranchs.

6. The telson is somewhat narrower distally, being nearly twice as long as broad, and there is a ventral spine at the end of the sixth abdominal segment. The outermost seta of Stage III is situated about half-way up the outer edge of the telson, while the second seta is reduced to a small hair on the outer angle.

7. The uropods have several setæ on each branch.

Stage V. Length 3·95 to 4·8 mm.

There is considerable variation among the specimens of this stage, indicating that the larvæ are not all of the same age. Probably there are in some cases intermediate moults; with the result that some larvæ unite the characters of Stages IV and V, and others those of V and VI.

But there is no doubt that a definite advance from Stage 4 can be thus defined :—

1. First antenna. Exopodite with two or three bundles of æsthetes. Endopodite sometimes two-jointed.

2. Second antenna. Endopodite two-jointed, nearly half as long as the scale.

3. Pereiopods one to four developed, biramous. The fifth usually a long unjointed rod, bent forwards and without setæ. In some cases it is fully formed.

4. Pleopods present as small buds which are simple or, in some cases, bilobed.

5. Telson narrow and parallel-sided, the proportion of width to length being from 1 : 2 up to 1 : 2·75.

6. All five pleurobranchs present. Epipodite on second maxillipede.

Stage VI. Length 3·85 to 5·38 mm.

This stage may be defined as follows :—

1. Second antenna. Flagellum from two-thirds to the whole length of the scale.

2. Fifth pereiopod fully developed and very long, reaching as far forwards as the eye, the carpus slightly expanded. In the first two pairs of legs there is a slight prolongation of the propodite—the first indication of the chelæ.

3. Pleopods developed as short-curved bilobed rods.

4. Telson narrow, the width less than one-third of the length.

5. Rostrum extending beyond the frontal lobe and down-curved. The smallest specimen of this stage seen—3·85 mm.—was exceptional in having the fifth leg fully developed, but no trace of pleopods.

Stage VII. Length 6·3 mm.

This is an ill-defined stage, differing little from Stages VI and VIII as follows :—

1. Second antenna. Flagellum a little longer than the scale.

2. First two pairs of legs subchelate.

3. Pleopods larger than in Stage VI, but without setæ.

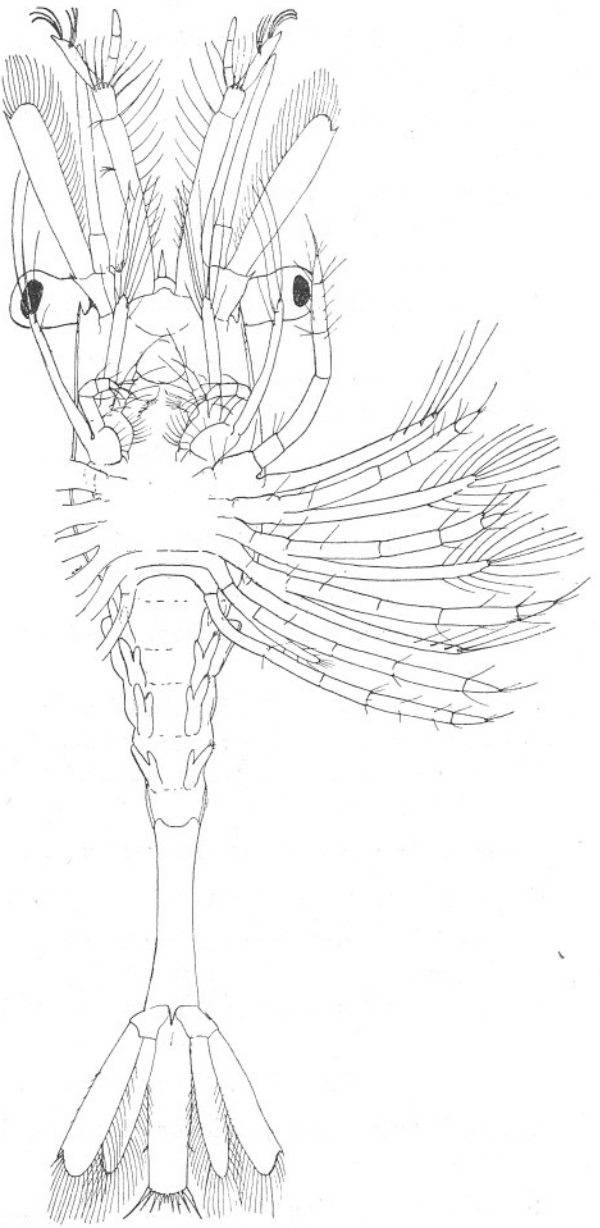


FIG. 6.—Stage VII, ventral view.

STAGE VIII. Length 5·7 to 7·2 mm.

This and the next stage also differ little from each other, but do undoubtedly represent distinct moults. In some cases, but apparently rarely, the larva moults directly from Stage VIII to the post-larval form, but as a rule the moult leads only to the slightly modified form of Stage VIII. This can not only be proved by examination of preserved specimens nearly ready to moult, but also by direct observation. Miss

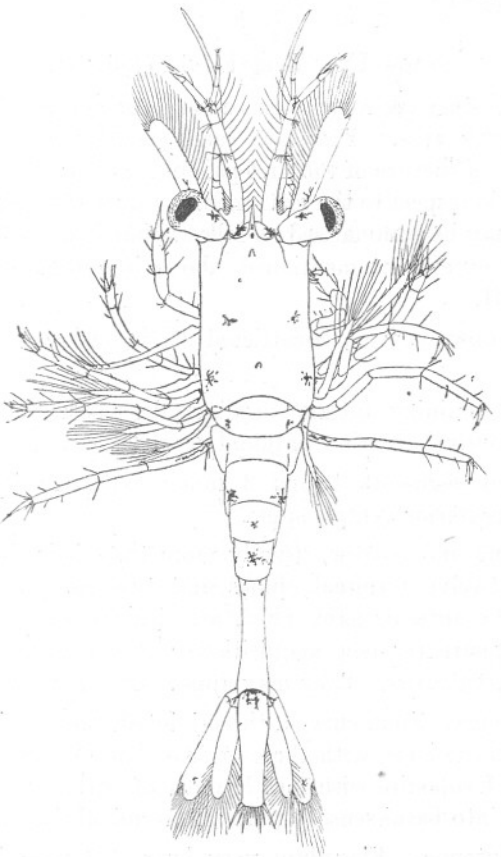


FIG. 7.—Stage VIII, dorsal view, showing arrangement of chromatophores.

Lebour has been good enough to give me the moulted skins of a larva reared by her in the Plymouth Laboratory, and I find that the first cast skin was of this stage and the second of my Stage IX.

Stage VIII has the following characters :—

1. Second antenna. The flagellum now greatly exceeds the length of the scale and may be jointed.

2. The first leg is short and stout, and chelate on the right side, but the chela is not quite fully developed and retains the larval spines.

3. In the second leg the prolongation of the propodite is scarcely more than half the length of the Dactylus.

4. Pleopods large, biramous, but without setæ.

It is worth noting that the smallest specimen, measuring (5·7 mm.), was about to moult to post-larval, while others of 7·7 mm. were preparing to moult to Stage IX.

Stage IX. Length 7·5 to 9·5 mm.

Larvæ of this stage are conspicuous and not uncommon in the plankton of the Plymouth area. They are easily recognised as belonging to Processa by the structure of the first pair of legs, but they also approach the adult form in respect to the rostrum and other details. The characters of this larva may be summarised as follows, but it must be remembered that with the exceptions mentioned above it shares these characters with Stage VIII.

1. Rostrum down-curved, constricted at the end where it bears two setæ.

2. Carapace retaining anterior, and usually posterior, median knobs and traces of ventral anterior marginal denticles.

3. Abdominal segments 1 and 2 much expanded laterally. Sixth segment with posterior ventral spine.

4. Telson long and narrow, usually more than four times as long as broad; with twelve terminal spines and two pairs of lateral spines (Fig 8, B). The anterior pair, which are situated rather on the dorsal surface, are apparently new acquisitions not corresponding to one of the original larval pairs. They may appear first in Stage VI.

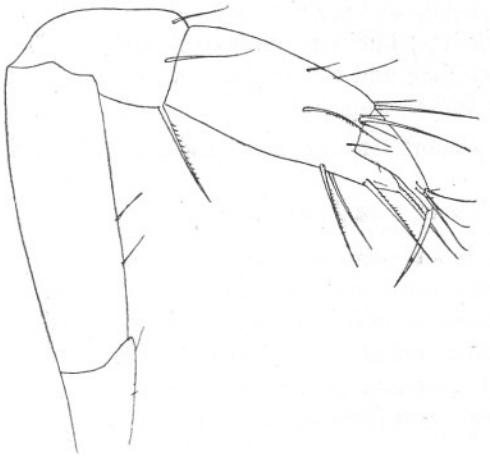
5. First antenna. Stem curved, three-jointed, the first joint expanded and notched at the base, with three or four " otic " setæ on the margin of the notch. Exopodite with four bundles of æsthetes and first sign of differentiation into basal sensory part and terminal flagellum.

6. Second antenna. Flagellum very long—3·2 mm. in a specimen 8·75 mm. long.

7. Mandibles still of larval form with distinct cutting and molar portions (Fig. 9, B).

8. Maxillipedes and maxillæ retaining larval form, with exception that the third maxillipede is very large and strong, as in the adult.

9. Legs 1 to 4 with well-developed exopodites, but these are much shorter than the endopodites. Leg 1 short and thick, simple on the



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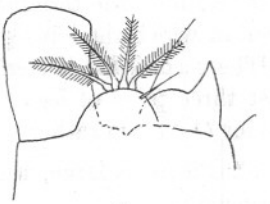

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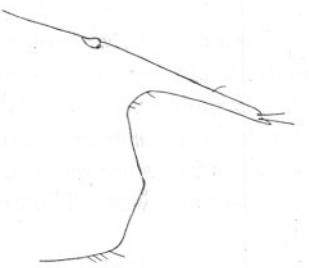

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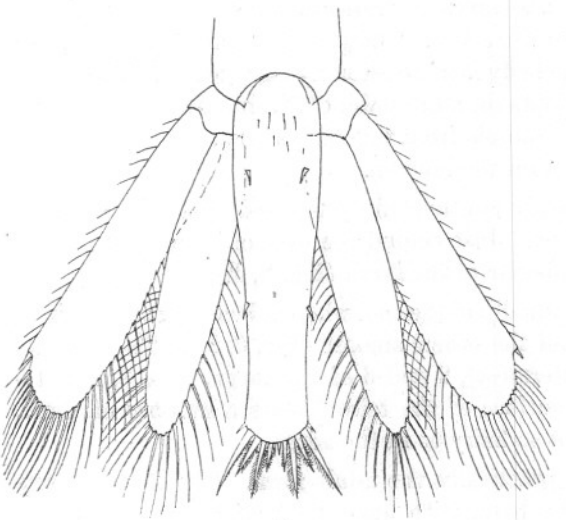

B.

D.

FIG. 8.

A. Stage IX. First pereiopod of right side.
B. ,, Telson and uropods.
C. 1st post-larval stage. Antennular lobe.
D. ,, ,, End of telson.
E. ,, ,, Anterior part of carapace and rostrum, showing trace of "dorsal organ."

left side, but chelate on the right (Fig. 8, A). The chela fully formed, but retaining the terminal spine of the larva. One individual has been seen in which the left leg was chelate and the right simple.

The second leg is slender, chelate, but with undivided carpus. The last three pairs of legs are very long and slender, carried horizontally, giving the larva rather a characteristic appearance.

10. Pleopods large, with very short terminal setæ, and first traces of retinacula.

The Colour of the Larvæ.

The larvæ at early stages are but faintly coloured, but in Stages VIII and IX chromatophores are numerous and the animal is conspicuous. The chromatophores usually have a central nucleus of opaque yellow (black in transmitted light) with orange-red branches. The general colour is therefore reddish, with glistening yellow points scattered over the body and legs. The fifth leg is conspicuously golden-yellow.

First Post-larval Stage. Length 9 to 10 mm.

With the next moult the larva is transformed into the post-larval stage, differing little from the adult. The general form is, however, but little changed, though the body is more laterally compressed. The young shrimp now, no doubt, adopts the adult habit of life, but several specimens found in an old plankton sample from the Eddystone area indicate that it does not always remain on the bottom.

1. The rostrum is sharply constricted at the end, bearing four setæ at the point of constriction. Just behind the base of it can still be seen a trace of the rounded tubercle of the larva (Fig. 8, E).

2. The telson tapers gradually to the end, where it bears six stout spines, the inner pair ciliated and the others smooth (Fig. 8, D). These spines correspond to setæ 1 (outermost), 2 and 6 of the larva, Nos. 3, 4 and 5 being lost. The dorsal surface of the telson bears a number of short, scattered hairs, but is not so hairy as in the adult.

3. The antennæ have practically the adult form. The first antenna is much expanded at the base, with an outer rounded process corresponding to the stylocerite of other Caridea. The antennular lobe is conspicuous, with four modified setæ and one simple hair (Fig 8, C). The outer flagellum has a swollen basal part of five joints bearing æsthetes, and a slender terminal part of three joints.

4. The mandible has the general form of that of the adult. It seems to me that the usual description of this type of mandible as being one from which the cutting part has been lost is misleading. Rather it appears that both molar and cutting parts are present, but that the

latter has, as it were, been folded over till it lies parallel to the molar portion, with a horseshoe-shaped depression between the two (Fig 9, C). The same appears to be the case in the Crangonidæ.

5. In the second maxilla the endopodite is a finger-shaped process, without lobes, and the setæ of the lobes of the protopodite are reduced. Four inner lobes are still traceable, but the second lobe of the coxopodite is very minute.

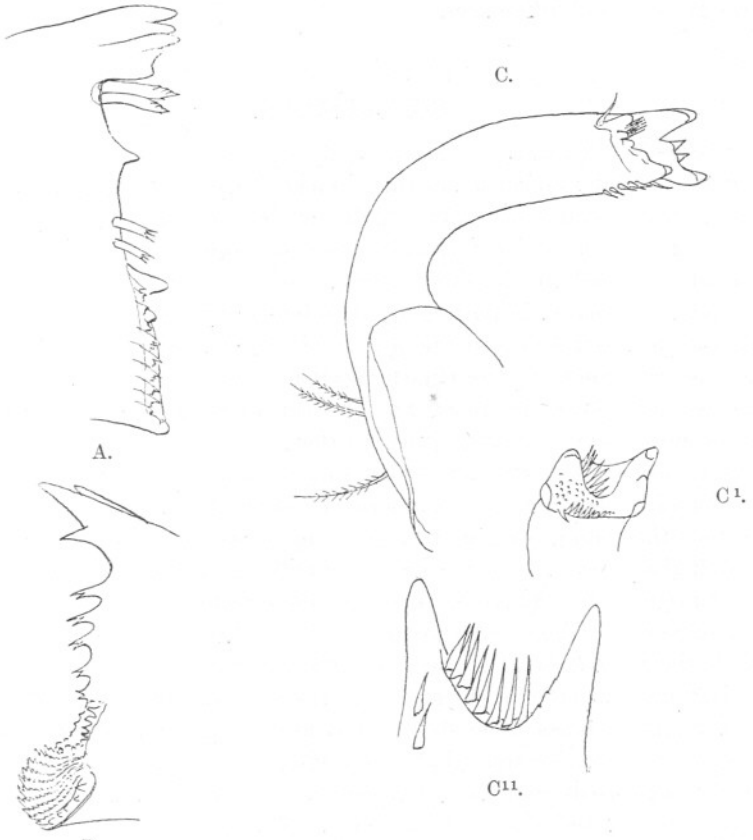

FIG. 9.

A. Mandible of larva in Stage V.
B. ,, ,, Stage IX.
C. ,, ,, 1st post-larval stage.
C¹. The same. End view.
C¹¹. ,, The end of the mandible seen from below.

6. The first maxillipede has a very large epipodite, but the basal joint on which it is borne seems to have lost its inner setiferous lobe.

The exopodite has now an expanded setiferous basal part, and the endopodite is reduced to an unjointed rod.

7. The second maxillipede has also a large epipodite, and the endopodite has assumed the adult form.

8. The form of the legs is that of the adult, with the exception that vestiges of the exopodites are retained until the next moult, and the merus of the second pair is not divided. The carpus is divided into about thirteen joints.

9. The pleopods and uropods have the adult form, but the former show no sign of sexual differences.

CONCLUSIONS.

The genus Processa was included by Spence Bate in his tribe Polycarpinea, which also contained the Alpheidæ, Hippolytidæ and Pandalidæ, the characters common to all being the slenderness of the second pereiopod and the division of its carpus into several joints; but this grouping, though accepted by Stebbing (1893), has not been adopted by recent authors. Ortmann, in particular, abandoned any larger divisions among the Caridea, and arranged the genera in families, placing the Processidæ in close relation with the Gnathophyllidæ and Crangonidæ. The same course was followed by Boas, who also considered Processa and Crangon to be most nearly related to each other, but placed Hippolyte on the direct line of ancestry from which sprang these two genera on the one hand and Palæmon and Pontonia on the other (1888, p. 67). Borradaile, on the other hand, reverted to a grouping of the families into tribes, and united the Processidæ with the Crangonidæ and others into one group, the Crangonoida. There is, therefore, an agreement in each case in the assumption of a close connection between the Processidæ and Crangonidæ, while the Pandalidæ are rather widely separated from both.

Systematists have for the most part refused to attach much importance to the larval stages as evidence of relationship, Ortmann in particular (1896) expressly stating that embryology is of very small value in classifying Crustacea; but it seems to me that larval stages should, when known, be taken into account. The question of the degree of importance to be attached to them is, however, a difficult one which I am not prepared to deal with on this occasion, but I believe that in this particular case the larval development does throw some light on the systematic position of the genus Processa.

It must be admitted that the larvæ of the Caridea are so remarkably uniform in general structure that it is difficult to discover characters which are of real systematic importance, and the difficulty is greatly increased by the fact that our knowledge of these larvæ is still extremely limited.

We know, for instance, the larval history of but one species (*Hippolyte varians*) among the Hippolytidæ, but the structure of certain larvæ assigned by Stephensen (1916) to the genus Spirontocaris shows that *H. varians* cannot be accepted as altogether typical of the family. Again, the very inadequate account of the larva of Pontonia given by Gourret (1884) indicates that the characters peculiar to the larvæ of Leander may be of generic rather than of higher importance, and it is difficult to distinguish among the generically different larvæ of the Crangonidæ characters which are common to all and distinctive of the family.

In the following table I have endeavoured to summarise the resemblances and differences between the larvæ of the four families in question, but I am well aware that the published information with regard to the Hippolytidæ is insufficient for a really satisfactory comparison.

The following conclusions seem to be justified by this table :—

1. The larvæ of the Pandalidæ and Processa agree in almost every detail of structure, and are, in fact, only separable with great difficulty.

2. In some respects these larvæ very closely resemble those of the Hippolytidæ, particularly those of Spirontocaris.

3. They differ in important respects from those of the Crangonidæ, while the Hippolytidæ resemble the Crangonidæ with regard to some of the features in which they differ from the Pandalidæ.

The larvæ of Pandalus and Processa, with their progressive development with scarcely any metamorphosis, and with their well-developed thoracic appendages with six or usually seven exopodites, are strikingly different from those of the Crangondiæ with their well-marked developmental stages and abrupt metamorphosis to the post-larval form. In the Crangonidæ the endopodites of the pereiopods are carried as unjointed functionless organs until the moult to the post-larval stage, as is the case with the Brachyura and Anomura. Not more than the first two pairs bear exopodites. *Hippolyte varians* resembles the Crangonidæ in the undifferentiated appearance of the endopodites of the pereiopods, and in the disappearance of the exopodites from the last three pairs ; but in Spirontocaris, not only are the endopodites of these legs developed as in Pandalus (Stephensen), but there may be exopodites on all but the last pair. In Hippolyte there are five larval stages and considerable metamorphosis, but it is not known whether the same is true in Spirontocaris.

It seems, therefore, that the conclusions to be drawn from a study of these larvæ are not in accordance with the accepted view of the relationship of the adults, for they undoubtedly negative any grouping of the genus Processa with the Crangonidæ, and tend to support a reinstatement

	Crangonidæ.	Hippolytidæ.	Pandalidæ.	Processa.
Larval Stages . .	Five. Complete metamorphosis at 5th moult	Five (Hippolyte). Metamorphosis less marked	More than five. Development gradual, metamorphosis very slight	As in Pandalus.
Carapace . .	Without dorsal or supraorbital spines. Anterior ventral edge denticulate	Supraocular spines small. Median tubercle behind rostrum. Anterior edge denticulate	Supraocular spines large. Median tubercle behind rostrum. Anterior edge not denticulate	Supraocular spines small. Median tubercle behind rostrum. Anterior edge minutely denticulate or smooth.
Rostrum . .	Generally broad at base	Short, slightly enlarged at base	Slender, not dilated at base. With dorsal teeth in mysis stage	Small, narrow
Telson . . .	Remaining broad at end till last stage. Posterior edge nearly straight (except in Pontophilus)	Becoming narrow in last stage. Posterior edge straight (Hippolyte)	Becoming narrow in last stage. Posterior edge deeply hollowed.	Becoming narrow. Posterior edge not deeply hollowed.
Abdominal Segments	Fifth always with a pair of spines. Third usually with one or two dorsal spines	A minute pair of spines on 5th segment in Spirontocaris?	Spines entirely absent (Pandalina). Sometimes present in Pandalus	A small pair of spines on 5th segment.
1st Antenna . .	Inner branch a straight, spinous process. Stem rather short and thick (except Pontophilus)	Inner branch represented by a seta in 1st stage. Stem short and stout (Hippolyte)	Inner branch as in Hippolyte. Stem long and slender	Inner branch as in Hippolyte. Stem long, slender, much curved.
1st Maxilla . .	Basipodite without an outer seta	Outer seta present	Outer seta absent	Outer seta present.
Pereiopods . .	Only one (Crangon) or two (Philocheras) with exopodite. All endopodites functionless	Only two with exopodite (Hippolyte) or four (Spirontocaris). Endopodites functionless (Hippolyte)	Three or four with exopodites. Endopodites functional	Four exopodites. Endopodites functional.
2nd Antenna . .	Scale not jointed at end in early stages. Endopodite a thick rod at first, swollen at base	Scale jointed at end. Endopodite a rod swollen at base and with one terminal spine or seta	Scale jointed. Endopodite at first a slender rod with two setæ; never swollen at base	Scale not jointed, very narrow. Endopodite as in Hippolyte.
1st Maxillipede .	Very small epipodite in Stage V	Small epipodite	Epipodite large	Epipodite large.

of Spence Bate's tribe of Polycarpinea. From this tribe the Alpheidæ must, however, be excluded, since they differ both in larval and in adult characters from the Hippolytidæ, Pandalidæ and Processidæ and approach the Palæmonidæ.

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Plymouth Peridinians. IV.

The Plate Arrangement of some Peridinium Species.

By

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With Figures I–V in the Text.

THE well-known *Peridinium ovatum* (Pouchet) is a common and widely distributed species. It was first described by Pouchet (1883) from the Mediterranean, and later more detailed figures were given by Schütt (1895), Fauré Fremiet (1908),* and Broch (1909). None of these figures agree with the plate arrangement found in the specimens from Plymouth. Jörgensen (1913) places the species in his section Humilia in the group Metaperidinium, on account of the supposed arrangement of the dorsal epithecal plates. However, on examining a large number of specimens from Plymouth it was found that the dorsal plates were not symmetrical as in the section Humilia (Fig. I, 1), but asymmetrical with the second

FIG. I.—Relation between the second anterio rintercalary plate and precingulars in the the sections Humilia and Pyriformia of the group Metaperidinium Jörgensen.

1. Humilia.
2. Pyriformia.

anterior intercalary touching both the third and fourth precingulars (Fig. I, 2). It would thus be placed in Jörgensen's section Pyriformia of the group Metaperidinium. Meunier (1910) agrees in his figures with Broch and Fauré Fremiet, but later (1919) he gives a figure (Plate XVI, Fig. 11), in which the dorsal plates are arranged as in the section Pyriformia, and exactly similar to the Plymouth specimens. Meunier, therefore, is the first to give the correct plate arrangement.

Specimens from the Isle of Man kindly sent by Sir William Herdman,

* Not his *P. ovatum*, which is another species, but his *P. lenticula*.

and from Cullercoats, Northumberland, have also been examined and found to agree with those from Plymouth; moreover, in plankton samples sent from Calicut, Madras, the species was abundant and the plate arrangement the same (Fig. II). There thus seems no doubt that

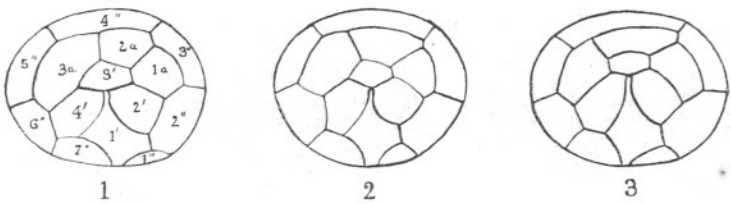

FIG. II.—Epitheca of *Peridinium ovatum* (Pouchet).
1. From Plymouth Sound, 18.2.21, 70 μ across.
2. From Plymouth Sound, 27.7.22, 70 μ across.
3. From Calicut, Madras, May, 1922, 70 μ across.

Peridinium ovatum belongs to the section Pyriformia, group Metaperidinium, of Jörgensen (Fig. III).

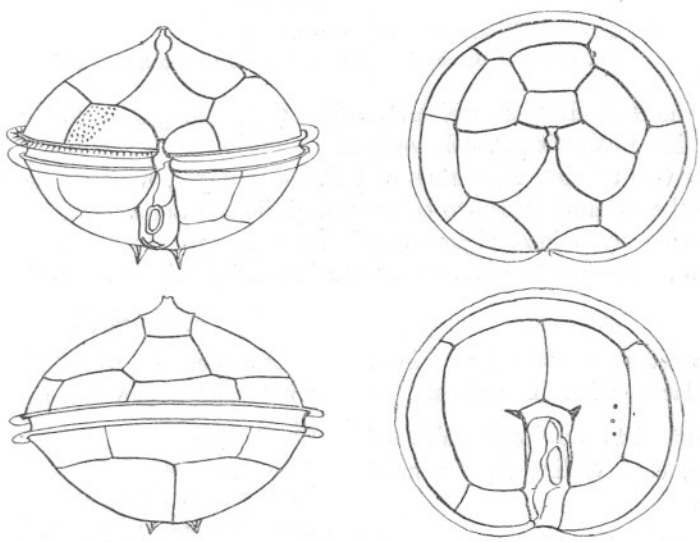

FIG. III.—*Peridinium ovatum* (Pouchet).
Plymouth Sound, 25.5.21, 64 μ across.

Another species recently found at Plymouth has possibly been confounded with *P. ovatum*. This is Broch's *P. curvipes* (1909), for which, as it is not identical with Ostenfeld's species of that name, I suggest the name *Peridinium sub-curvipes*. Paulsen (1911) and Pavillard (1916) have already pointed out that this is a different species which Broch described from Spitzbergen and those from Plymouth exactly agree

with it. The dorsal plates (Fig. IV) are symmetrical, and show that it belongs to the section Humilia, group Metaperidinium; thus it differs from the original *P. curvipes* of Ostenfeld, which also occurs in Plymouth and which belongs to the section Paraperidinium. Pavillard's species

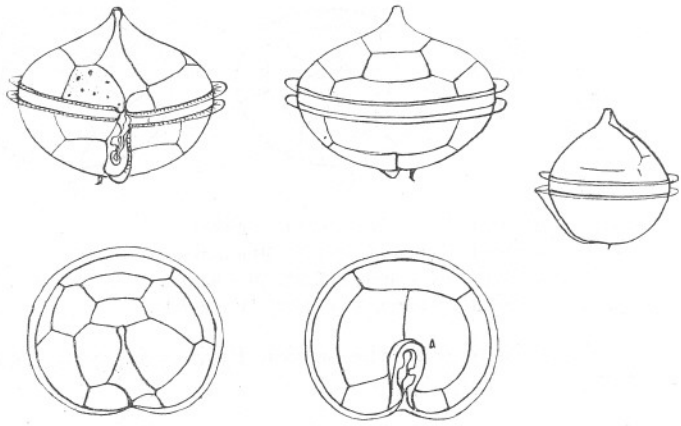

FIG. IV.—*Peridinium sub-curvipes* nom. nov.
=P. curvipes Broch, 44 μ across, English Channel, Station E2, 14.3.23.

from the Golfe du Lion, which he assigns to *P. curvipes*, is closely related, if not identical, with *P. sub-curvipes*.

The two species, *P. ovatum* and *P. sub-curvipes*, are both lenticular, the cell contents pinkish to colourless, girdle equatorial with strong lists supported by spines, right-handed, belonging to the group Metaperidinium. The differences are set forth in the following table :—

P. ovatum.	*P. sub-curvipes.*
Diameter up to 84 μ. Theca granular or with fine spines.	Diameter up to 52 μ. Theca with a few large pores or sometimes spines.
Faint lists on both sides of sulcus, each ending in a winged spine.	Conspicuous list on left side, ending in a spine, spine on right not connected with list.
Dorsal epithecal plates, as in the section Pyriformia.	Dorsal epithecal plates, as in the section Humilia.
First apical oblique with fairly long central side on left.	First apical very oblique with very short central side on left.
Conspicuous ridge on anterior margin of third apical.	No ridge on anterior margin of third apical.

Another species occurring fairly frequently at Plymouth, but usually

singly, calls for attention as to its plates—*Peridinium claudicans* Paulsen (1907). Paulsen himself does not describe the plates in detail, although he says it is similar to *P. oceanicum var. oblongum*. Certainly at the first glance affinities with this species are suggested, but on careful examination of the dorsal epithecal plates it is seen to be of the right oblique type with the second anterior intercalary related to both the third and fourth precingulars (Fig. V), and thus belonging to the section

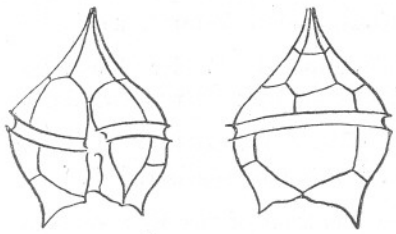

FIG. V.—*Peridinium claudicans* Paulsen.
75 μ across, Plymouth Sound, 30.5.21.

Tabulata of the Orthoperidinium group, not to the Oceanica section, where it is related only to the fourth precingular. Barrows (1918) figures this species from Sousaleto, California, with similar dorsal plates, but regards the specimen as abnormal. As in all the Plymouth specimens examined the plates are as described above it seems that this is the typical arrangement, and any showing the Oceanic type must be regarded as a different species.

To sum up, therefore, we place the species above-mentioned in the following sections and groups :—

Group.	*Section.*	*Species.*
Orthoperidinium Jörgensen.	Tabulata Jörgensen.	*Peridinium claudicans* Paulsen.
Metaperidinium Jörgensen.	Pyriformia Jörgensen.	*Peridinium ovatum* (Pouchet).
	Humilia Jörgensen.	*Peridinium sub-curvipes* nom. nov.

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Coccolithophora pelagica (Wallich) from the Channel.

By

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With a Figure in the Text and 1 Table.

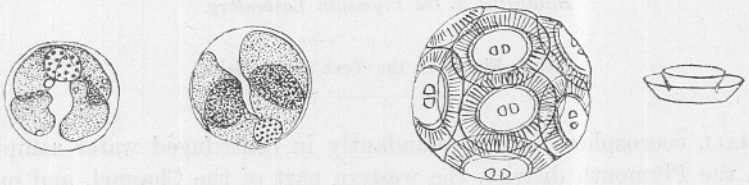
A SMALL coccosphere occurs abundantly in centrifuged water samples from the Plymouth district, the western part of the Channel, and outwards towards the Irish Sea and the French coast. This agrees with the species described by Ostenfeld (1899) as *Coccosphæra atlantica*, from the North Atlantic, which Lohmann (1902) considers identical with Wallich's *Coccosphæra pelagica* (1877). Lohmann, therefore, unites the two species as *Coccolithophora pelagica*, and in this he is followed by Ostenfeld (1908), the generic name of *Coccosphæra* being preoccupied by Perty (1852) for a small green flagellate.

The chief difference between *C. pelagica* and *C. atlantica* is in the number of coccoliths (16 to 36 in the former, 10 to 17 in the latter). The overlapping of the margins of the Coccoliths in *C. atlantica* is another difference, but it appears likely from Wallich's drawings that he had only taken the inner margins into consideration, and, therefore, regarded the coccoliths of *C. pelagica* as not overlapping. His measurements, which cover an extensive range, embrace those of *C. atlantica*. It seems, therefore, that *C. atlantica* is to be regarded as the same species as *C. pelagica*, the coccoliths having a similar form, and that Lohmann and Ostenfeld are justified in bringing them together.

Coccolithophora pelagica thus includes Murray and Blackman's *C. pelagica* (1898), Huxley's " Coccospheres " (1868, Plate 4, Figs. 6, c, d, e, and 7, b and c), and Ostenfeld's *C. atlantica* (1899, 1900). The coccoliths described by Joly and Dixon (1897) and the coccospheres by Dixon (1900) from the Irish Sea also belong to this species.

The Channel specimens agree entirely with Ostenfeld's *C. atlantica* and Dixon's *C. pelagica*, having usually from 10 to 11 coccoliths (in the largest 15 to 17), and the cells vary little in size, the average diameter being from 19 to 25 μ, 27 μ being the largest seen. Dixon found no chromatophores; Ostenfeld (1908) describes it as having 2 (?). In the Channel specimens examined alive typical dark yellow chromatophores were present. By dissolving off the coccoliths four chromatophores in each cell could be made out, which were

so close together that they appeared as one when still covered by the skeleton. There is apparently no flagellum ; in the living organism none could be seen, which is in accord with other observers. The nucleus. which is as Ostenfeld describes it, with minute masses of chromatin regularly distributed throughout, occurs at the base of the chromatophores, where they come close together.



A. B. C. D.

FIG. I.—*Coccolithophora pelagica* 22 μ across. 12.10.22. Station E2, 20m.

A. Treated with methyl green and 5% acetic, showing chromatophores and nucleus.

B. Treated with weak acetic, showing the same.

C. Alive.

D. Coccolith.

Weak acetic acid dissolves the coccoliths easily and leaves the chromatophores yellow ; methyl green with 5% acetic dissolves the coccoliths almost at once, and stains the nucleus and chromatophores so that they are plainly seen.

The accompanying table gives records of this species from the water-bottle samples taken by Dr. Atkins during various hydrographic cruises in the Channel and outside in 1921–1922. The letters refer to the stations given by him in the chart (1922, page 754), the explanation of which are here repeated :—

L1. In the fairway of Plymouth Sound below the Laboratory near the Mallard Buoy. Lat. 50° 22′ N., long. 4° 08′ W.

L2. In the fairway between the western extremity of the Breakwater and the Cornish coast, north of Cornwall.

L3. Off Rame Head, on the line between the Breakwater Lighthouse and the Eddystone.

L4. Half-way between Rame Head and the Eddystone. Lat. 50° 15′ N., long. 4° 13′ W.

L5. Eddystone, 10 miles S. 42° W. from Breakwater Lighthouse.

L6. Half-way between the Eddystone and the International Station. E1, viz. 5 miles on a S.W. course. Lat. 50° 06′ N., long. 4° 20′ W.

TABLE

of records of *Coccolithophora pelagica* (Wallich), its separate coccoliths, and *Pontosphæra Huxleyi* Lohmann in the area of the hydrographic cruises, 1921–22, X=only one seen in 10 c.c., R=more than one, less than 4, C=common, in 10 c.c., S=surface, m=metres.

Year	1921.															1922.																	
Month	August.						October.			November.			December.																					
Day	12	15	16	16	23	23	18	18	18	9	10	12	12	12	12	6	6	11	11	11	11	11	11	11	11	11	12	12	12	12	12	12
Locality	E1	E1	E1	E1	X6	X6	L3	E1	E1	E1	E3	N2	E1	E1	E1	L3	E1	L4	L6	E2	E2	E2	E2	E2	E2	E3	E3	E7	E7	E7	N2	N2	N2
Depth	S	S	S	25 m.	15 m.	70 m.	S	5+15 m.	50 m.	65 m.	S	S	S	25 m.	70 m.	S	25 m.	S	S	S	5 m	25 m.	50 m.	85 m.	5 m.	25 m.	S	25 m.	65 m.	S	25 m.	85 m.
T° C.	16·13	15·7	16·01	13·59			15·99	15·52	15·40	14·97	13·9	13·43	12·95	13·15	13·11	8·9	10·52	8·9	9·8	10·5	10·6	4	10·64	10·62	10·62	10·76	10·79	9·9	10·18	10·18	10·2	10·25	10·26
Salinity °/₀₀	—	35·11	35·11	35·19	—	—	35·18	35·30	35·20	35·33	35·48	35·28	35·40	35·41	35·42	34·93	35·33	35·16	35·33	35·26	35·4	2	35·41	34·45	35·39	35·43	35·45	35·29	35·31	35·28	35·21	35·23	35·20
pH	—										8·20	8·14	8·14	8·14	8·12	8·11	8·14	8·09	8·11	8·12	8·1	4	8·14	8·14	8·14	8·13	8·13	—	8·14	8·14	8·12	8·14	8·14
Coccolithophora pelagica					X		X	X	X		X		X	X	X		X	X	X	X	X		X	R	X	X	X	X	X	X			
Coccoliths of ,,										X		X		X			X	X	X		X		C	X		X	X	X	R	X	R	C	C
Pontosphera Huxleyi	X	X	X	X		X										X																	

Year	1922.																															
Month	March.										May.																July.					
Day	15	15	15	29/30	29/30	29/30	29/30	29/30	29/30	29/30	22	22	22	22	22	22	23	23	23	23	24		24	23	23	23	11	11	12	12		
Locality	E1	E1	E1	E1	E3	E3	E3	N1	N1	N2	L1	L2	E1	E1	E2	E2	N1	N1	N1	N2	L1		L2	E3	E3	E3	E2	E2	E3	E3		
Depth	S	5 m.	70 m.	S	S	25 m.	100 m.	50 m.	100 m.	10 m.	S	S	40 m.	50 m.	10 m.	40 m.	10 m.	25 m.	100 m.	75 m.	S		S	10 m.	25 m.	100 m.	S	10 m.	25 m.	50 m.		
T° C.	9·6	9·64	9·62	9·7	9·9	10·20	10·16	9·82	9·83	9·40	14·4	13·0	10·10	10·08	11·80	10·62	11·58	11·60	10·50	10·28	13·	17	13·4	11·20	11·62	11·05	13·9	12·74	11·83	11·72		
Salinity °/₀₀	35·32	35·28	—	35·35	35·41	38·41	35·38	35·23	35·25	35·19	31·62	33·27	35·40	35·39	35·29	35·31	35·26	35·28	35·33	35·20	—		—	35·29	35·29	35·31	35·37	35·35	35·31	35·32		
pH	8·16	8·16	8·16	8·16	8·17	8·17	8·17	8·16	8·16	8·15	8·22	8·23	8·16	8·14	8·19	8·15	8·18	8·17	8·16	8·15	8·	29	8·25	8·18	8·17	8·16	8·17	8·17	8·17	8·15		
Coccolithophora pelagica				X	C	R	C	X	R	X	X		X		R	X	X	R	R	X	X		X	X	X	X						
Coccoliths of ,,	X	X	X											X												X	X	X	X	X			
Pontosphæra Huxleyi												X																					

Year	1922.																							
Month	September.								October.															
Day	22	22	22	22	22	22	22	22	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Locality	L3	L4	L5	L6	E1	E1	E1	E1	L1	L2	L4	L5	L6	E1	E1	E1	E1	E1	E1	E1	E1	E1	E1	E1
Depth	S	S	S	S	10 m.	25 m.	50 m.	70 m.	S	S	S	S	S	S	5 m.	10 m.	15 m.	20 m.	40 m.	50 m.	60	m.	70 m.	
T° C.	14·6	14·4	14·4	14·6	14·21	14·17	14·17	14·17	13·8	14·1	14·25	14·3	14·2	14·2	14·10	14·08	14·06	14·06	14·01	14·00	14·62		14·62	
Salinity °/₀₀	35·23	35·31	38·32	35·31	35·30	35·31	35·29	35·29	33·03	34·63	35·22	35·33	35·24	35·31	35·25	35·26	35·28	35·28	35·25	35·27	35·	26	35·29	
pH	8·20	8·20	8·20	8·22	8·22	8·20	8·18	8·18	8·12	8·17	8·20	8·20	8·20	8·20	8·20	8·20	8·20	8·20	8·20	8·20	8·20		8·20	
Coccolithophora pelagica	X	X	X	X	R	X	X	X	X	X	X	R	X	X	C	R	R	R	X	R	R		X	
Coccoliths of ,,				X																				
Pontosphæra Huxleyi																								

To face page 272.

E1. Ten miles S.W. from the Eddystone. Lat. 50° 02′ N., long. 4° 22′ W. Depth 40 fathoms. Bottom samples 70 metres.

E1, E2, E3 lie on an approximately S.W. course from Plymouth to Ushant; N1 and N2 are on a line joining Ushant and Cork Harbour, N2 being south of the Bishop Light, Scillies; E7 is S.E. from the Wolf Light off the Lizard; X6 Whitsand Bay, approximately in a line with E1.

From these records *C. pelagica* is seen to occur close to the shore and outwards, reaching as far as N2 and E6, which are some way outside the Channel. The only time it is recorded as common is at E3 (both at the surface and at 100 metres) in March, and at E1 at 5 metres in October (1922). These are both stations about equally distant from land (ca. 20 miles), E1 from Plymouth, E3 from the French coast. The species occurs at all depths from the surface to 100 metres, which was the greatest depth at which the water-bottle was used. It appears to be an oceanic form which can come near the shore, but has its usual habitat in the open sea. It lives in water of pH value between 8·11 and 8·29, at a salinity of 31·62 to 35·48°/$_{oo}$, and can occur between the temperature 9°·40 and 16°·7 C. It was found to be most numerous at the temperature 9°·9–14°·10 C., salinity 35·25°/$_{oo}$–35·38°/$_{oo}$, pH8·16–8·17 in March and October. It occurs almost all the year round, being apparently less common in June, July, and August than in the remaining months. It is probably very abundant in the Plymouth district, for it is present inside many of the plankton organisms which were examined for food both from inside the Sound and outside as far as Station E1, and its coccoliths have long been known to be common in the bottom deposits from the Sound and outside. The coccoliths are frequently found built into the cases of tintinnids, as described by Lohmann (1913), but usually in the Channel it was *Tintinnopsis beroidea* and *T. ventricosa*, and only a few were used among the usual sand grains in each case.

The following animals contained coccoliths: *Calanus finmarchicus* (13), *Pseudocalanus elongatus* (10), *Temora longicornis* (5), *Acartia clausi* (17), *Centropages typicus* (3), *Corycæus anglicus* (4), zoëa of Crab indet. (3), zoëa of *Corystes* (4), *Porcellana* larva (4), *Eupagurus* larva (3), *Crangon* larva (2), *Pandalus* larva (5), *Galathea* larva (2), *Gebia* larva (1), *Axius* larva (1), *Calocaris* larva (3), Euphausiid larva (5), *Echinospira* (1), *Auricularia* (1), Terebellid larva (9), Polynoid larva (1), *Actinotrocha* (1). In the case of a *Calanus* (Polperro N.N.W., Looe N.$\frac{1}{2}$ E., 25.8.21) several whole coccospheres (*Coccolithophora pelagica*) were still in the stomach, and in another a whole *Pontosphæra Huxleyi*. In one small Pouting, *Gadus luscus* (3 mm. long), a whole *Coccolithophora pelagica* was found (Lebour, 1917). It is not often, however, that the whole organisms are seen in

the alimentary canal of any of these animals. As is shown, the coccoliths have been found inside copepods, larval decapods, larval mollusks, larval annelids, larval echinoderms, and *Actinotrocha*.

Pontosphæra Huxleyi Lohmann, the only other coccosphere so far known in this district is found less frequently, but may easily be passed over owing to its small size. Dr. Allen has very often obtained pure cultures of this species from samples of water taken from various parts of the Sound and outside, so that it must really be exceedingly common. The present records show it to occur in August, February, and May, from comparatively near the shore (X6, L2, and L3) and from E1, from the surface to the bottom (70 metres). The only record of it inside an animal is in the above-mentioned *Calanus*. It occurred in the microplankton in 1916 fairly frequently, when the water samples were regularly centrifuged (Lebour, 1917).

It is thus seen that these two species are common in the district, and so far no others have been observed. From the notes given above they must be important members of the phytoplankton, and, at any rate in the case of *Coccolithophora*, are noteworthy as nourishment for the plankton-eating animals.

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Factors Affecting the Durability of Silk Plankton Tow-nets and Young Fish Trawl-nets.

By

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OWING to the combined action of bacteria, sunlight, sea-water, and general wear and tear the costly silk tow-nets when in constant use are only found to last a few months, or with less use for over twelve months. The young fish trawl-nets, made of a hemp material known as "stramin," if used several times a week are expected to last over three months.

It is the general impression that silk nets should be washed in fresh-water and dried after every time they are used.

It was suggested by Dr. G. Barr, of the National Physical Laboratory, that an antiseptic bath might prolong the life of such nets through lessening bacterial action. One is, however, limited in a choice of preservatives by the fact that it is necessary to avoid anything that may clog the fine meshes, cause shrinkage, or be likely to damage the fibre. Since formalin is in constant use for preserving plankton hauls it appeared worth while trying it on the nets also. It is, however, known that acids injuriously affect fabrics, and commercial formalin is as acid as pH2·8 when purchased, and produces acid on standing, in sunlight especially. The formalin was accordingly rendered slightly more alkaline than sea-water by the addition of a little borax, which remains as a buffer to neutralise acidity when generated.

Exposure tests were made with the various fabrics stretched loosely on frames upon the Laboratory roof and subjected to treatment as detailed below.

YOUNG FISH TRAWL-NET.

1. Dry control, stored in dark.
2. Frame exposed to weather on roof, March 14 to April 27, 43 days.
3. Soaked daily for 10 minutes in sea-water for 35 out of 43 days, exposed on roof as No. 2.
4. As No. 3, save that once a week, six times in all, the sea-water treatment was followed by 10 minutes in 5% formalin brought to pH8·5–9·0 with borax.

Tensile tests were carried out at the National Physical Laboratory, as set forth in the report which is appended, but taking the figures for the control as one hundred the various treatments resulted in deterioration, as shown by the following table :—

YOUNG FISH TRAWL.

	1. Control.	2. Exposure.	3. Exposure + Sea-water.	4. As 3 + Formalin.
Weft	100	94	93	83
Warp	100	83	88	75

It is at once obvious that the occasional treatment with formalin is injurious, and that sea-water has no more effect than the rain received by Nos. 2 and 3 alike. Within the six weeks, however, the general weathering has been considerable, and might be more noticeable with the intenser light of summer and during the longer days. Since, however, the net is expected to last only for about three months it seems that mechanical injuries must add largely to its rate of deterioration.

TOW-NET, silk, double anchor, lion and cable brand, 25 mesh per inch.

1. Dry control, stored in dark.
2. Frame exposed on roof, 43 days.
3. Ten minutes sea-water.
   Ten minutes fresh-water.
   Dried on roof (if fine), total exposure 14 hours.
   Treated as above, 35 out of 43 days.
   Stored in dark.
4. As No. 3, but treated for 10 minutes daily with 5% neutralised formalin after sea-water and before fresh-water washing.

The percentage results of the tensile tests are shown as before.

TOW-NET, 25 mesh.

	1. Control.	2. Exposure.	3. Sea-water, fresh-water.	4. As 3, with formalin.
Weft	100	57	89	86
Warp	100	53	89	86

It is clear that exposure to light results in rapid deterioration of the silk, whereas the sea- and fresh-water treatments have had far less effect. Formalin treatment is again shown to be distinctly injurious.

TOW-NET, silk, 100 mesh per inch, same brand.

1. Dry control, stored in dark.
2. Kept in 5% borax formalin.
3. Ten minutes daily in sea-water, 35 days out of 43 ; kept on roof 43 days.
4. As No. 3, but treated with fresh-water for ten minutes daily after sea-water.

The percentage results are as follows :—

TOW-NET, silk, 100 mesh.

	1. Control.	2. In 5% Formalin.	3. Exposed, sea-water.	4. As 3, but rinsed.
Weft	100	90	50	47
Warp	100	94	46	45

The foregoing figures show that formalin, even in the dark, has a deleterious influence on silk. Furthermore, the damage to the 100-mesh silk due to exposure results in a loss of over half its strength in six weeks, even in spring. Instead of improving matters the extra washing in fresh-water has resulted in an additional weakening.

SUMMARY AND RECOMMENDATIONS.

1. Sunlight is the main cause of weakening of nets and tow-nets when exposed but not in use, and is more important than bacterial action. As weakening progresses mechanical injuries are likely to assume an important place as damaging agents.

2. Formalin, tried as a preservative, has been found to be injurious.

3. Rinsing in fresh-water, after using silk nets in salt-water, has been proved to damage the nets when carried out daily. The practice is accordingly not recommended ; nevertheless it seems advisable to rinse out a net in fresh-water before prolonged storing, as it remains drier.

4. As far as possible all nets should be kept from sunlight, once they have been dried. They should then be stored without further treatment. The deterioration of silk nets is specially rapid when exposed to sunlight. When possible dry in the shade in a breeze.

Details of the tests made by Dr. Barr are contained in a report from the Director of the National Physical Laboratory which runs as follows :—

The samples consisted of pieces about 18 inches square of three fabrics marked YFT, 1–4, tow-net 25, 1–4 and tow-net 100, 1–4, which had

been variously treated. Owing to shrinkage, some of the squares were distorted ; in the tensile tests the slope of the cross threads was neglected and the threads under test merely stretched as evenly as possible between the grips.

The changes in weight per square metre were found to vary in much the same sense as the changes in dimensions : consequently the ends and picks were counted accurately and no exact determinations of weight were made, since these would not enable any deductions to be made as to gain or loss of substance from the fabrics.

For the tensile tests six test pieces were cut in each direction from each sample of dimensions such as to allow them to be frayed down to about 2 inches in width, leaving 7 inches between grips. (Four of the test pieces from tow-net 100, 4 had to be taken 1 inch shorter.) In view of the above-mentioned contraction, the width to which the pieces were frayed was not a constant but was such as to include the same number of threads in corresponding test pieces : the table gives the breaking load for a piece containing the stated number of threads.

The number of threads per inch was counted in nine places in each direction for each sample. The numbers given in the table below stand in positions which are related to the position of the count in the square of fabric.

YOUNG FISH-TRAWL.—Rate of loading 200 lb. per minute.

Breaking loads of weft pieces containing 40 picks.

	Y.F.T. 1 Weft. lbs.	Y.F.T. 2 Weft. lbs.	Y.F.T. 3 Weft. lbs.	Y.F.T. 4 Weft. lbs.
	244·0	227·0	221·0	199·0
	244·0	222·0	221·0	211·0
	243·0	216·5	223·5	161·0
	239·0	223·0	226·0	190·0
	237·0	222·0	255·0	202·0
	224·0	229·0	183·0	221·5
Mean :	238·5	223·2	221·6	197·4

Breaking loads of warp pieces containing 30 ends.

	Y.F.T. 1 Warp. lbs.	Y.F.T. 2 Warp. lbs.	Y.F.T. 3 Warp. lbs.	Y.F.T. 4 Warp. lbs.
	186·5	161·5	170·0	154·0
	203·0	144·0	180·0	138·0
	201·0	166·5	162·0	152·0
	217·0	174·0	179·0	134·0
	198·0	177·5	190·0	168·0
	195·0	170·0	172·0	150·0
Mean :	200·1	165·6	175·5	149·3

Weft threads per inch.

18·2	18	18·2	18	18·5	18·5	16·8	18	17·5	19	21·8	18·8
18·5	18	18·5	17·5	18·5	17	17·5	18·5	17·5	18·5	20·2	18·5
18	18·2	18·5	17·5	18·5	17·2	17·5	19	17	18·8	21·8	19·5
Mean 18·2			Mean 17·9			Mean 17·7			Mean 19·6		

Warp threads per inch.

14·5	14·2	14·5	15	14·8	15·21	15·5	14·8	15·2	16	15·2	15·8
14·5	14·2	14·5	15	15	15	15	15	15	16·8	16·2	17·5
14·5	14·2	14·5	15	15·2	15·2	15	15·2	15·2	16	15·8	16·8
Mean : 14·4			Mean : 15·0			Mean : 15·1			Mean : 16·2		

TOW-NET, 25 MESH.—Rate of loading 100 lb. per minute.

Breaking loads of weft pieces containing 50 picks.

Townet 25—1 Piece A. lbs.	Townet 25—2. Piece B. lbs.	Townet 25—3. Piece A. lbs.	Townet 25—4. Piece B. lbs.
99·0	61·0	82·0	68·5
93·5	53·0	91·0	87·5
93·0	54·0	88·0	88·0
92·5	54·0	76·0	79·0
97·0	50·0	86·0	86·0
92·0	52·5	79·0	80·0
Mean : 94·5	54·1	83·6	81·5

Breaking loads of warp pieces containing 50 ends.

Warp.	Warp.	Warp.	Warp.
90·0	46·0	83·5	74·5
91·0	50·0	78·5	80·0
88·5	52·0	76·0	75·0
90·0	46·0	82·0	79·5
92·0	50·0	80·0	80·0
93·0	48·0	85·0	79·0
Mean : 90·7	48·6	80·8	78·0

Weft threads per inch.

25·5	25·5	26	27	28	27·5	27·5	27·8	27·5	27·5	27·5	28
26·5	26·5	26·5	27	26·8	26·5	27	26·8	26·5	27·5	28·5	28
25	25·5	25·5	26·8	26·8	26·8	27·5	27·5	27	27·5	28	28
Mean : 25·8			Mean : 27·0			Mean : 27·2			Mean : 27·8		

Warp threads per inch.

25·5	25	25	26	25·2	25·2	25·8	25·2	25·5	26	25·5	25·5
25·5	25	25	26	25·5	25·2	25·8	26·5	25·5	26	25·5	25·8
25·5	25	25	26	25·5	25·2	26	25·8	25·5	26	26	25·8
Mean : 25·2			Mean : 25·5			Mean : 25·7			Mean : 25·8		

TOW-NET, 100 MESH.—Rate of loading 80 lb. per minute.

Breaking loads of weft pieces containing 200 picks.

Tow-net 100—1. Piece B. lbs.	Tow-net 100—2. Piece A. lbs.	Tow-net 100—3. Piece A. lbs.	Tow-net 100—4. Piece B. lbs.
67·5	65·5	29·0	23·0
62·0	60·0	37·0	30·0
69·0	62·5	33·5	30·5
66·5	65·0	28·0	33·0
72·0	68·5	36·0	38·0
70·0	42·5	38·0	36·5
Mean : 67·8	60·6	33·6	31·8

Breaking loads of warp pieces containing 200 ends.

68·0	63·0	29·5	25·0
71·0	66·0	34·0	30·5
69·5	65·5	16·0	32·0
69·5	60·0	35·0	34·0
69·5	64·0	33·0	31·0
61·0	66·0	39·0	30·0
Mean : 68·1	64·1	31·1	30·4

Weft threads per inch.

99	100	100	110	109	110	110	119	110	115	116	111
95	95	96	110	108	109	104	119	107	107	112	104
99	100	96	111	110	111	114	119	109	113	119	115
Mean : 98			Mean : 110			Mean : 112			Mean : 112		

Warp threads per inch.

96	98	99	112	107	105	106	103	103	102	100	100
96	97	102	111	107	105	109	99	101	103	100	102
95	98	100	109	107	105	102	99	99	101	98	98
Mean : 98			Mean : 108			Mean : 102			Mean : 100		

(Signed) J. E. PETAVEL, Director.
Per G. BARR.

Note on an Apparatus for Determining the Quantity of Dissolved Gases in Sea Water, and in Fluids containing Organic Matter.

By

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With Figures I–IV in the Text.

An apparatus was devised with the primary object of determining the atmospheric nitrogen and oxygen dissolved in sea water from on board ship in fine weather. It was found that the apparatus could be used at sea in fine weather, but owing to the difficulty of manipulation when any sea was running there was a possibility of error which necessitated duplicate determinations being made, each of which took about twenty minutes. In the Laboratory, on the other hand, the apparatus gives rapid and reasonably accurate results, and may be of use for the estimation of oxygen or other dissolved gases in fluids which contain organic matter, rendering Winkler's method of oxygen determination impossible, and where there is an insufficient quantity of fluid and time to carry out extraction of the gases by means of a mercury pump.

The apparatus was made as shown diagramatically in Fig. I, consisting of a glass bulb filled with mercury, with the necessary means of evacuating it and trapping any air leak which may occur in the process. It is mounted in a weighted teak box with hinged door and can be let down by a line to any desired depth in the sea, the tap t opened by a messenger and the charge of sea water (4·59 c.c. in this particular apparatus) drawn in, as shown in Fig. II. The apparatus is then drawn up, tap t and screw pinch cock s closed, and the bulb evacuated by lowering the mercury reservoir and opening tap q (Fig. III). Tap q is then closed and the apparatus shaken for two minutes. This is easily done by clamping the hinged door of the case to a vertical support and swinging the case to and fro.

The pressure is then restored by raising the mercury reservoir, and the resultant bubble of gas forced through the fine bore pressure tubing x into the capillary of the gas analyser (Fig. IV), where it collects at the top of the bulb B. The rubber plug r is then closed, disconnecting the bulb

and capillary from the water in the jacket J surrounding the gas analyser, the apparatus inverted, and by screwing B on to the rubber nipple *n*, filled with water, the bubble of gas is forced into the graduated capillary. The end of the capillary is dipped into a 40 per cent NaOH solution, when by screwing and unscrewing B the NaOH solution is drawn into

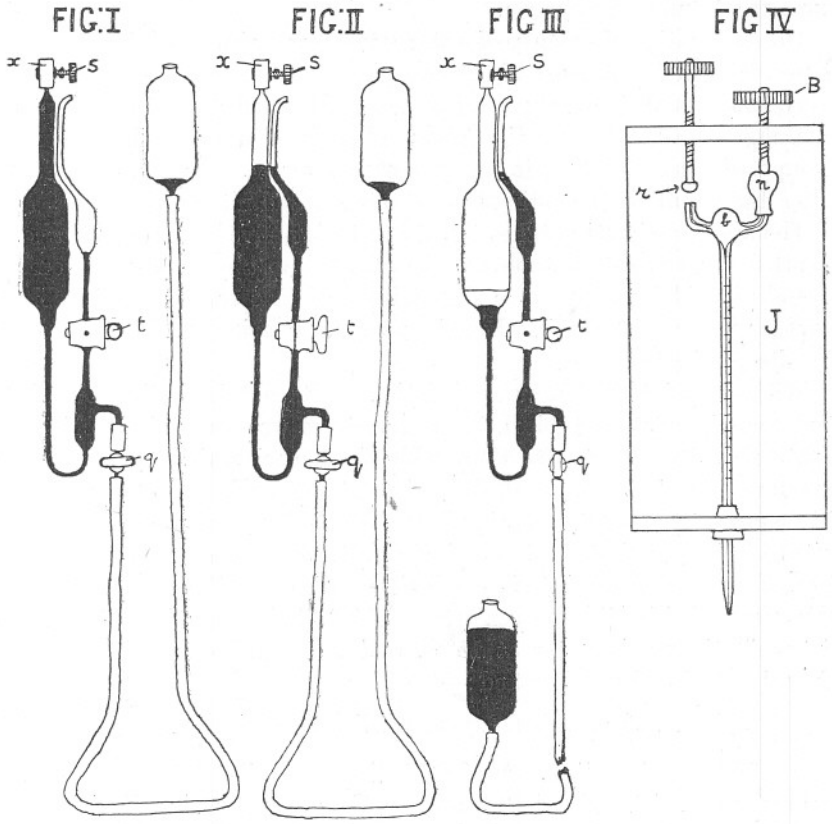

FIG. I.—Extraction apparatus ready to receive charge of fluid.

FIG. II.—With charge of fluid drawn in.

FIG. III.—With Torricellian vacuum above the fluid.

FIG. IV.—Apparatus for analysis of the bubble of gas extracted from the charge of fluid, surrounded by a water-jacket J.

the capillary and the bubble of gas washed in it, the carbon dioxide being absorbed.

In the case of sea water the gas extracted consists of oxygen atmospheric nitrogen and a part only of the carbon dioxide.

The length of the column of residual oxygen and atmospheric nitrogen extracted from the 4·59 c.c. of sea water is then read, together with the temperature of the water jacket of the gas analyser, and its volume at

N.T.P. calculated. The column of gas is washed in the same manner in alkaline pyrogallol and the residual volume of atmospheric nitrogen noted. To clean out the capillary and bulb of the gas analyser ready for the next estimation, all that is necessary is to open *r*, when fresh water from the jacket J washes out the alkaline pyrogallol remaining, together with the column of nitrogen.

One evacuation of a charge of water extracts practically all the dissolved gases, the partial pressure of the gases in the Torricellian vacuum being very small, and equilibrium being nearly attained after two minutes' shaking. A second extraction gives only a very minute bubble, which, composed mainly of CO_2 in the case of sea water, does not materially alter the result of the estimation of oxygen and nitrogen.

The above estimation takes twenty to twenty-five minutes at shallow depths up to twenty fathoms. The charge can also be taken from a vessel of fluid by means of a siphon inserted into the fine bore rubber capillary tube *x* in Fig. I, when the whole estimation can be completed in fifteen minutes.

With regard to the accuracy of the results obtained, the following two experiments are typical. A vessel of sea water at 15° C., chlorine content 1·95 per cent, was thoroughly shaken with air at atmospheric pressure (bar. 767 mm.) and allowed to stand for four hours at 15° C. in a constant temperature bath. The content of oxygen and atmospheric nitrogen in sea water at varying temperatures has been tabulated from a very careful series of experiments by Charles Fox (*Publication de Circonstance*, No. 41. Copenhagen, 1907), and according to these determinations this water at 15° C. and 767 mm. barometric pressure should contain when saturated:—

5·86 c.c. at N.T.P. of oxygen per litre of water.
11·25 ,, ,, nitrogen ,, ,,

From three determinations made by the apparatus described it was found to contain:—

	5·6	c.c. at N.T.P. of oxygen per litre of water.
	5·6	,, ,, ,, ,, ,,
	5·7	,, ,, ,, ,, ,,
Mean value	5·63	,, ,, ,, ,, ,,
	11·55	c.c. at N.T.P. of atmospheric nitrogen per litre of water
	11·3	,, ,, ,, ,, ,, ,,
	11·4	,, ,, ,, ,, ,, ,,
Mean value	11·41	,, ,, ,, ,, ,, ,,

In another experiment water was withdrawn by means of a siphon from a large vessel of sea water at room temperature after thorough

mixing, and five determinations of its oxygen and nitrogen content were made with the above apparatus and of its oxygen content by means of Winkler's method.

	Oxygen in c.c. at N.T.P. per litre of water.		Atmospheric nitrogen in c.c. at N.T.P. per litre of water.
	By above apparatus.	By Winkler's method.	By above apparatus.
	4·62	4·86	10·31
	4·74	4·85	10·31
	4·62	4·85	10·54
	4·62	4·84	10·43
	4·62	4·77	10·19
Mean value	4·64	4·83	10·36
Maximum departure from mean value	+0·10	−0·06	+0·18

I am indebted to Mr. C. C. Stockman for very carefully standardising the sodium thiosulphate solution used in the determinations by Winkler's method, and also for making several determinations by the same method as a check upon my own.

Marine Biological Association of the United Kingdom.

Report of the Council, 1922.

The Council and Officers.

Four ordinary meetings of the Council were held during the year, at which the average attendance was eleven. An inspection of the Laboratory was carried out by a committee of six members, who visited Plymouth for the purpose. The Council desires to express its thanks to the Royal Society and to the Linnean Society, in whose rooms its meetings have been held.

The Plymouth Laboratory.

The buildings, machinery and fittings have been maintained in a state of efficiency. An electric motor and pump have been installed for circulating the sea-water through the Aquarium and Laboratory tanks, and fresh provision has been made for the supply of air to the tanks. It is anticipated that the new arrangements will reduce considerably the running costs.

The ejector used for pumping sea-water from the sea to the large reservoirs has undergone an extensive overhaul and is working efficiently.

A small dynamo for the production of direct current for physiological work has been fitted in the engine room and is worked by the gas engine.

As we are unable again to obtain the use of the room at the Corinthian Yacht Club for the Easter Classes in Marine Biology, the Council has decided to erect a class room at the back of the Laboratory, with dimensions 40 ft. by 16 ft. It is hoped that this will be completed by March, 1923. A considerable part of the sum necessary for this new building has been subscribed by former students and workers at the Laboratory.

The Boats.

The steam trawler-drifter *Salpa* has worked with great success during the year and has proved very efficient. Her sea-going qualities are much appreciated both by the naturalists and the crew. She has

recently been fitted with a small deck laboratory, which has been built aft of the engine-room casing. This will greatly facilitate the scientific work and also add to the comfort of those carrying out the researches.

The *Salpa* visited Hull in September during the meeting of the British Association, where she was inspected by many marine biologists and other men of science, who expressed themselves most favourably in regard to her suitability for marine research work.

The general collecting in Plymouth Sound has again been done with the sailing boat *Anton Dohrn*.

The *Oithona* was sold to Prof. G. Gilson of Brussels, to be used for fishery and biological investigations under the direction of the Belgian Government. The sum realised was £775.

The Staff.

Two additions have been made to the scientific staff during the year, Mr. C. F. A. Pantin, of Christ's College, Cambridge, having been appointed Assistant Physiologist, and Mr. Owen D. Hunt, of the University of Manchester, Assistant Naturalist. In other respects the staff is as last year.

The Director, Dr. E. J. Allen, F.R.S., was President of Section D (Zoology) at the Hull meeting of the British Association for the Advancement of Science. Special attention was given during the meeting to questions relating to Marine Biology and Fishery Research.

Occupation of Tables.

The following naturalists have occupied tables at the Plymouth Laboratory during the year :—

H. Baker, Oxford (Plymouth Fauna).
H. Barcroft, Marlborough (General Biology).
G. Barkas, London (Kinema-photography).
T. T. Barnard, Oxford (Development of *Gyge branchialis*).
Miss L. Batten, London (Gracilaria).
L. E. Bayliss, Cambridge (General Zoology).
N. J. Berrill, Bristol (General Zoology).
L. R. Brightwell, London (Illustrations of Plymouth Fauna).
W. De Morgan, Plymouth (Protozoa).
Dr. H. W. Dudley, London (Insulin from dogfish pancreas).
Mrs. C. Essenberg, California (Invertebrate Larvæ).
Miss L. N. Fredericks, London (Porifera).
Prof. W. Garstang, Leeds (Ctenophores and Fisheries).
Miss S. Garstang, Oxford (Development of Botrylloides).
J. Gray, Cambridge (Effect of Ions on Ciliary Movement).
R. Gurney, Norwich (Decapod Larvæ).
Prof. W. D. Henderson, Bristol, Ray Lankester Investigator (Comparative Anatomy of Fishes).
A. D. Hobson, Cambridge (General Zoology).
H. W. Lomas, London (Kinema-photography).
A. G. Lowndes, Marlborough (General Biology).

O. C. A. Monro, Oxford (Histology of de-differentiation in Clavellina)
J. R. Norman, London (Larval and post-larval Fishes).
F. A. Potts, Cambridge (Teredo).
Dr. B. Prashad, Calcutta (Fishes).
A. Ramalko, Portugal (Fishes).
A. D. Ritchie, Manchester (Chemistry of Fish Muscle).
F. S. Russell, Cambridge (Larval and post-larval Fishes).
Miss L. Russell, London, Ray Lankester Investigator (Nudibranch Metamorphosis).
J. T. Saunders, Cambridge (Hydrogen ion concentration of Sea- and Fresh-water).
Mrs. E. W. Sexton, Plymouth (Gammarus).
Dr. C. Shearer, F.R.S., Cambridge (Development of Pomatoceros).
Miss Webb, Birmingham (General Zoology).
J. F. G. Wheeler, Bristol (Formation of yolk in some Teleosts).
L. R. Wormald, Leeds (Pycnogonida).
Miss E. Worsnop, Plymouth (Oysters).
C. M. Yonge, Edinburgh (Teredo).

The usual Easter Vacation Course in Marine Biology was conducted by Dr. J. H. Orton, and was attended by thirty-two students from Oxford, Cambridge, London, Birmingham and Edinburgh.

Mr. E. W. Shann brought a class of eight boys from Oundle School for a practical course, and these were joined by two boys from Leighton Park School, Reading, and one from the Training Ship *Conway*.

Mr. A. G. Lowndes brought a class of seven boys from Marlborough College.

General Work at the Plymouth Laboratory.

Work on the pelagic young of Teleostean fishes has been continued by Mr. R. S. Clark, who is preparing concise descriptions with figures for the identification of the species at critical stages from Northern and Southern North Sea and from Channel material.

Special attention is being given to the distribution of the various stages and to the duration of pelagic life, with a view to determining the dispersal of the species until the adoption of the bottom habitat and during their first year of existence.

Information has been collected as to the decline of the Channel Hake fishery, while a good deal of general work has been done towards a more comprehensive study of the life history of this important food fish. Investigations on age and growth rate are being continued on the considerable number of adolescent Hake which have been a feature of the recent catches.

The first of a series of papers on the genus Raia was published in Vol. XII, No. 4 of the Journal. This series is being continued on a comprehensive scale and will include a systematic survey of the Rays and Skates.

Mr. E. Ford, in connection with his study of the food of fishes, has made extensive use of Petersen's Bottom Sampler, and a large amount of material has been collected. In the neighbourhood of Borough Island

in Bigbury Bay, an area of the sea-bottom particularly rich in food for the plaice and dab has been located. The small lamellibranch, *Syndosmya alba*, has been found to occur there in one instance as thickly as 1800 individuals per square metre, together with good numbers of the brittle star *Amphiura filiformis*, and the lamellibranch *Cultellus* (=*Solen*) *pellucidus*. Additions to the records of the local fauna are being made in the course of the working up of the material, among which may be mentioned the taking of the Sea Pen *Virgularia mirabilis* in muddy sand in Plymouth Sound, and a more extensive distribution of the hydroid generation of *Corymorpha nutans*.

The investigation on the mortality of oysters in the Thames Estuary, which Dr. J. H. Orton has been carrying out during the last two years in connection with the Ministry of Agriculture and Fisheries and the Oyster Planters Association, has now been completed and the full report which Dr. Orton has prepared awaits publication. The investigation has involved an intensive study of the bionomics of the oyster, and has led to a number of observations of fundamental importance.

In the intervals Dr. Orton has continued his general studies of the bionomics of marine animals, including experiments on hibernation phenomena (in Clavellina) in relation to temperature variations, and observations on the mode of feeding of Aurelia; experiments on rate of growth of marine invertebrates in a polar region (at Spitzbergen) and at various places in England, with special attention to Cardium, Crepidula and oysters in relation to the conditions controlling both growth and sex-phenomena.

In the coming year Dr. Orton hopes to concentrate mainly on the publication of results already obtained.

Dr. Lebour has continued studying the plankton of the Plymouth area and the food of the plankton organisms. Since the publication of her preliminary paper on this subject, she has specialised on the observation of live animals in the Plunger Jar. These consisted chiefly of Coelenterates, particularly medusae, and their food and methods of feeding were investigated. Interesting results were obtained and it is clearly seen that many medusae (at least 10 species), even some of the smallest, and also the ctenophore Pleurobrachia can and do catch, eat and digest small fishes. Certain species, such as *Sarsia tubulosa* apparently feed entirely on Crustacea, and several are omnivorous, such as *Turris pileata*, which can eat a young Cephalopod as big as itself, or make a meal of many copepods or two or three small fishes. The strength of the tentacles of these medusae is relatively enormous and they are used just as an expert angler uses his line.

An Aurelia was reared in the Plunger Jar from the smallest ephyra to a breadth of $1\frac{1}{4}$ inches and during the whole of this time it ate a quantity of food, chiefly small fishes, showing that feeding by means of ciliary currents is not the only method in this species.

The investigation into the food of other members of the plankton by dissection has brought out some interesting facts, notably in the copepods

and larval crustacea, and it is shown that some are chiefly vegetarians, e.g. Calanus and most of the common copepods and young decapod larvae, and others carnivorous e.g. the copepod Anomalocera, crab megalopae and even the youngest lobsters.

Dr. Lebour has also continued her work on Peridinians and has nearly finished a fully illustrated account of the Northern species which it is hoped will be published shortly. A short paper on some of these which are of special interest is now ready.

Whilst examining centrifuged water samples it was found that the small coccosphere *Coccolithophora pelagica* was abundant alive, from nearly all the hydrographical stations. A short paper on this is now ready for publication.

Hydrographical stations were worked by Mr. H. W. Harvey in the *Salpa*, including five cruises to Ushant and thence to the Bristol Channel. The data obtained have been sent to the Bureau of the International Council for publication, and to Dr. Le Danois of the French Fishery Department for co-ordination with the French and Irish results. Dr. Atkins has determined hydrogen ion concentrations of samples of sea-water on board as soon as they were taken. A comparison of the hydrographical results obtained during the years 1921 and 1922 is of interest, the range of salinity during 1921 being unusually high and breaking the biannual sequence of lower ranges of salinity in odd than in even years. In 1921 the temperature, in round figures, of the deep water below 25 metres at Station E. 1. (22 miles S.W. of Plymouth) rose to 14° C. in mid-September and reached a maximum of 15½° C. in mid-October, falling again slowly at first and reaching 13° C. in December. In 1922 the temperature reached a maximum of 14° C. towards the end of September, falling rapidly after mid-October to 11° in December. The salinity rose very rapidly from mid-September to mid-November in 1921, indicating an influx of relatively warm water from the south-westward, while in 1922 the salinity was at a maximum in July, falling slowly to December, indicating a movement of relatively cold low salinity water from the Irish Sea and the northward into the mouth of the English Channel.

Investigations on the life-history and hereditary characters of *Gammarus chevreuxi*, which are being made by Mrs. E. W. Sexton, have yielded results of much interest. Chief attention has been paid this year to the question of the effect of changes of temperature on the rate of breeding and the rate of development of these Amphipods. Miss A. R. Clark has given great assistance in the experimental work.

Mr. W. De Morgan, who has worked at the Laboratory throughout the year, is preparing an account of the ciliated protozoa which are found in the Laboratory tanks or are brought in with dredged material.

Mr. J. F. G. Wheeler, of Bristol University, who is working with a grant from the Department of Scientific and Industrial Research, has taken up the study of the formation of yolk in the eggs of Teleostean fishes.

Physiological Laboratory.

Further equipment of general utility has been purchased and some pieces of special apparatus as required.

From an economic point of view the sea may be regarded as a blue pasture for the raising of marketable fishes. Farmers know that a certain acreage will support or fatten a definite number of cattle, but similar precise information regarding the sea is lacking. In the latter depth as well as area has to be considered.

The problem of supplying information on this point has been approached in three ways. Firstly, following the late Prof. Benjamin Moore, by studying the change in the hydrogen ion concentration of sea-water due to the abstraction of carbonic acid by algae during photosynthesis. This leads to an estimate of 250,000 kilograms of carbohydrate photosynthesized, as a minimum value, between July and December, per square kilometre of sea in the western English Channel throughout the column of water from top to bottom, namely through about 83 metres on an average. Changes in the reaction of the water as land is approached were studied also, with a view to their possible relation to the movements of anadromous fishes.

Secondly, a calculation has been based upon the respirable organic matter in sea-water as shown by the production of carbonic acid in stored sea-water and made evident by the change in colour of added indicator. From this it may be concluded that the amount of respirable organic matter calculated as a hexose sugar is 500,000 kilograms per square kilometer from top to bottom as before. The method needs further investigation.

Thirdly, some information appears to be given from a study of the seasonal variations in the phosphate content of the water, including smaller plankton. Analyses carried out by the Government chemist, upon samples taken during the hydrographic cruises, have shown that even far out to sea the variations in P_2O_5 are very similar to those recorded by D. J. Matthews for inshore water (Journal XI, N.S., 1916–18). The relation of phosphate content to season and depth is now being worked out in greater detail by a more complete set of samples. The preliminary results show a change from winter to summer corresponding to the removal of 240 kilograms of P_2O_5 per square kilometre to 80 metres. Taking the content of P_2O_5 in whole undried fish as 1.0 per cent after Sempolowski, the amount removed should suffice for 24,000 kilograms assuming it to be used by fish only. This is considerably below the previous estimates, which related to carbohydrate, not to fish.

The three approximations given in the foregoing paragraphs are being studied in greater detail.

An attempt is also being made to determine the effect of the hydrogen ion concentration of the medium upon the solubility of various salts. It has been ascertained that ferric salts are completely precipitated while the solution is still acid, whereas traces of ferrous salts remain

unprecipitated till somewhere in the region of pH8. Manganese salts are still more soluble, considerable quantities remaining in solution till pH9 or over.

It has been found that brom thymol blue may be used as an *intra vitam* stain for determining the reaction of cells. The reagent does not penetrate as readily as neutral red, but is of use because it covers a more acid range. It also increases in colour at the alkaline end, whereas neutral red decreases.

Mr. C. F. A. Pantin, who has only been here during the last quarter, is studying amoeboid movement as a simple case of protoplasmic contraction. Effects of changes in osmotic pressure and reaction are being followed up systematically. In general the osmotic effects are similar to those observed by Loeb in the leucocytes of Limulus. It was further shown by means of the two indicators previously mentioned that an increase of acidity with accompanying increase in the fluidity of the cell contents precedes the protrusion of a pseudopodium. This appears to be an observation of fundamental importance.

Mr. Pantin has also found that the projection of the image of a set of standard buffer tubes with added indicator, may be effected by means of the condenser, so that they are seen in the field alongside the object whose pH is being estimated colorimetrically under the microscope. This is a considerable aid in comparing the colour of the object with the standards.

Dr. Dudley, of the Medical Research Institute, Hampstead, has recently worked here also and prepared an extract of the pancreas of the dogfish which preliminary experiments had led him to believe might contain insulin.

Published Memoirs.

The following papers, the outcome of work done at the Laboratory, have been published elsewhere than in the Journal of the Association :—

ALLEN, E. J. *The Progression of Life in the Sea.* Report British Association, Hull, 1922. Also abstract in "Nature," Vol. CX, 1922, pp. 448–453 and in Amer. Nat., Vol. LVI, 1922, pp. 481–583.

ATKINS, W. R. G. *The Hydrogen Ion Concentration of the Soil in Relation to Animal Distribution.* "Nature," Vol. CVIII, 1921, p. 568.

ATKINS, W. R. G. *Some Factors affecting the Hydrogen Ion Concentration of the Soil and its Relation to Plant Distribution.* Scient. Proc. Roy. Dub. Soc., Vol. XVI (N.S.), 1922, pp. 369–413.

ATKINS, W. R. G. *The Hydrogen Ion Concentration of Plant Cells.* Scient. Proc. Roy. Dub. Soc., Vol. XVI (N.S.), 1922, pp. 414–434.

ATKINS, W. R. G. *Measurements of the acidity and alkalinity of natural waters in their biological relationships.* Salmon and Trout Magazine, 1922, Sept., pp. 184–198.

ATKINS, W. R. G. *The Hydrogen Ion Concentration of Soils and Natural Waters in Relation to Animal Distribution.* Ann. Rep. Brit. Assoc., 1922. Abstract only.

ATKINS, W. R. G. *Some Physical and Chemical Factors which affect Plant Distribution.* Ann. Rep. Brit. Assoc., 1922. Abstract only.

ATKINS, W. R. G. *The Hydrogen Ion Concentration of Natural Waters and some etching reagents in Relation to Action on Metals.* Trans. Faraday Soc., 1922. Read Nov. 20th.

DEBAISIEUX, P. *Haplosporidium nemertis, nov. sp.* C. R. Soc. Biol. Paris, T. LXXXII, 1919, pp. 1399–1400.

DEBAISIEUX, P. *Quelques Protozoaires parasites des Chitons et des Patelles.* C. R. Soc. Biol. T. LXXXII, 1919, pp. 1400–1402.

DEBAISIEUX, P. *Haplosporidium (Minchinia) chitonis Lamk., Haplosporidium nemertis, nov. sp. et le groupe des Haplosporidies.* La Cellule, T. XXX, f. 2, 1920.

DEBAISIEUX, P. *Note sur deux Coccidies des Mollusques : Pseudoklossia (?) patellae et P. chitonis.* La Cellule, T. XXXII, f. 2, 1920.

GOODRICH, E. S. *On a new Type of Teleostean Cartilaginous Pectoral Girdle found in young Clupeids.* Journ. Linn. Soc. Zool., Vol. XXXIV, 1918–22, pp. 505–509.

HARINGTON, C. R. *A Note on the Physiology of the Ship-worm (Teredo norvegica).* Biochem. Journ., Vol. XV, 1921, pp. 736–741.

HARINGTON, C. R. *Report of work done at the Marine Biological Station, Plymouth, July 1st to September 18th,* 1920. Dept. Scient. and Industrial Research. Deterioration of Structures in Sea-water. Second (Interim) Report of the Committee of the Inst. C. E., 1922, pp. 35–42.

HUXLEY, J. S. *Dedifferentiation in Echinus Larvæ, and its Relation to Metamorphosis.* Biol. Bull., Vol. XLIII, 1922, pp. 210–234.

LEIGH-SHARPE, W. H. *The Comparative Morphology of the Secondary Sexual Characters of Elasmobranch Fishes.* Journ. Morph., Vol. XXXV., 1921, pp. 359–380.

MCMURRICH, J. P. *Note on the Systematic Position and Distribution of the Actinian Sagartia luciæ.* Proc. Zool. Soc., 1921, pp. 729–739.

ORTON, J. H. *The Blood-cells of the Oyster.* "Nature," Vol. CIX, 1922, p. 612.

ORTON, J. H. *Occurrence of a Crystalline Style in the American Slipper Limpet (Crepidula fornicata) and its Allies.* "Nature," Vol. CX, p. 149, 1922.

ORTON, J. H. *The Mode of Feeding of the Jelly-fish Aurelia aurita on the Smaller Organisms of the Plankton.* "Nature," Vol. CX, p. 178, 1922.

ORTON, J. H. *The Phenomena and Conditions of Sex-change in the Oyster (O. edulis) and Crepidula.* "Nature," Vol. CX, 1922, p. 212.

ORTON, J. H. *On the Occurrence of the Archiannelids, Saccocirrus and Protodrilus, on the South and West Coasts of England.* "Nature," Vol. CX, 1922, p. 574.

ORTON, J. H. *The Relationship between the common Hermit-crab (Eupagurus bernhardus) and the Anemone (Sagartia parasitica).* "Nature," Vol. CX, 1922, p. 735.

WINCKWORTH, R. *Notes on the British Species of Anomia.* Proc. Malac. Soc., Vol. XV, 1922, pp. 32–34.

The Library.

Both the general library and the special physiological library have continued to increase during the year, and the collection of books dealing with the science of the sea is now one of the most complete in the country.

The thanks of the Association are again due to numerous Government Departments, Universities, and other Institutions at home and abroad for copies of books and current numbers of periodicals presented to the Library. Thanks are due also to those authors who have sent reprints of their papers to the Library.

Vice-Presidents, Officers, and Council.

The following is the list of gentlemen proposed by the Council for election for the year 1923–24 :—

President.

Sir E. Ray Lankester, K.C.B., LL.D., F.R.S.

Vice-Presidents.

The Duke of Bedford, K.G.
The Earl of Stradbroke, C.V.O., C.B.
Viscount Astor.
Lord Montagu of Beaulieu.
The Earl of Balfour, K.G., F.R.S.
The Right Hon. Sir Arthur Griffith-Boscawen.
The Right Hon. Austen Chamberlain, M.P.
G. A. Boulenger, Esq., F.R.S.
W. B. Hardy, Esq., Sec.R.S.
Sir Arthur Steel-Maitland, Bart., M.P.
Prof. W. C. McIntosh, F.R.S.

COUNCIL.

Elected Members.

L. A. Borradaile, Esq.
W. T. Calman, Esq., D.Sc., F.R.S.
H. H. Dale, Esq., C.B.E., M.D., F.R.S.
G. P. Farran, Esq.
Prof. J. Stanley Gardiner, F.R.S.
Prof. W. Garstang, D.Sc.
J. Gray, Esq.
Julian S. Huxley, Esq.
Sir Frederick W. Keeble, Sc.D., F.R.S.
Prof. E. W. MacBride, D.Sc., F.R.S.
H. G. Maurice, Esq., C.B.
T. H. Riches, Esq.
J. A. Robertson, Esq.
Prof. D'Arcy Thompson, C.B., F.R.S.

Chairman of Council.

Sir Arthur E. Shipley, G.B.E., D.Sc., F.R.S.

Hon. Treasurer.

George Evans, Esq., 1 Wood Street, London, E.C.2.

Hon. Secretary.

E. J. Allen, Esq., D.Sc., F.R.S.,
The Laboratory, Citadel Hill, Plymouth.

The following Governors are also members of Council :—

G. P. Bidder, Esq., Sc.D.
E. T. Browne, Esq.
R. Holland-Martin, Esq., C.B. (Prime Warden of the Fishmongers' Company).
W. T. Brand, Esq. (Fishmongers' Company).
George Evans, Esq. (Fishmongers' Company).
His Honour Judge Chapman (Fishmongers' Company).
Lothian D. Nicholson, Esq. (Fishmongers' Company).
Major Nigel O. Walker, O.B.E. (Fishmongers' Company).
Prof. G. C. Bourne, D.Sc. F.R.S. (Oxford University).
Sir Arthur E. Shipley, G.B.E., D.Sc., F.R.S. (Cambridge University).
Sir William A. Herdman, C.B.E., D.Sc., F.R.S. (British Association).

THE MARINE BIOLOGICAL ASSOCIATION

Dr. *Statement of Receipts and Payments for the*

GENERAL

	£	s.	d.	£	s.	d.
To Balance from 31st December, 1921 :—						
Cash at Bankers	738	3	7			
Cash in hand	12	0	5			
Due from Special Fund	692	5	3	1,442	9	3
,, Grants :—						
Ministry of Agriculture and Fisheries Grant from Development Fund	1,900	0	0			
Royal Society	30	0	0	1,930	0	0
,, Subscriptions				51	9	0
,, Composition Fees				15	15	0
,, Sale of Specimens (*less* purchases)				201	15	0
,, ,, Fish (*less* expenses)				10	13	10
,, ,, Nets, Gear, and Apparatus				72	10	10
,, Tank Room Receipts				30	0	3
,, Interest on Investments :—						
New Zealand Stock				5	15	0
,, Sale of Journal				9	3	5
				£3,769	11	7

The Association's Bankers hold on its behalf :—
£410 14s. 8d. New Zealand 4% Stock, 1943–63.
£500 0s. 0d. War Savings Certificates.
£78 9s. 4d. 4% War Loan 1929–42 Registered Stock.

SPECIAL

Capital

	£	s.	d.
To Donations	101	1	0
,, Balance :—			
Amount due to General Fund	591	4	3
	£692	5	3

Three Months 1st January to 31st March, 1922. 6r.

FUND.

	£ s. d.	£ s. d.
By Salaries :—		
Director	212 10 0	
Physiologist	197 10 0	
Naturalists	495 0 0	
Hydrographer	112 10 0	1,017 10 0
,, Laboratory Wages (including National Insurance and Pension)		374 3 9
,, Annual Upkeep of Library		76 18 7
,, Annual Upkeep of Laboratories and Tank Room :—		
Buildings and Machinery	44 12 10	
Gas, Coal, Water, etc.	76 19 11	
Chemicals, Apparatus, etc.	195 16 2	
Rent, Rates, Taxes, and Insurance	33 6 9	
Travelling	9 16 4	
Stationery, Postages, Telephone, Carriage, and Sundries	117 8 10	478 0 10
,, Annual Maintenance and Hire of Boats :—		
Wages (including Diet Allowance and National Insurance)	404 10 9	
Coal and Water	121 5 2	
Maintenance and Repairs with Nets, Gear, and Apparatus	255 13 9	
Boat Hire	4 11 7	
Insurance	8 15 0	794 16 3
,, Balance :—		
Cash at Bankers (*less* loan £300)	425 12 9	
Cash in hand	11 5 2	
Due from Special Fund	591 4 3	1,028 2 2
		£3,769 11 7

FUND.

EXPENDITURE.

	£ s. d.
By Balance from 31st December, 1921 :—	
Amount due to General Fund	692 5 3
	£692 5 3

Examined and found correct,

(Signed) W. T. BRAND.
L. D. NICHOLSON.
J. O. BORLEY.
N. E. WATERHOUSE.

3 *Frederick's Place*,
Old Jewry, London, E.C. 2
24*th April*, 1923.

THE MARINE BIOLOGICAL ASSOCIATION

Dr. *Statement of Receipts and Payments for the*

GENERAL

	£ s. d.	£ s. d.
To Balance from 31st March, 1922 :—		
Cash at Bankers, *less* Loan from Bankers, £300.....	425 12 9	
Cash in hand.....	11 5 2	
Due from Special Fund	591 4 3	1,028 2 2
,, Grants :—		
,, Ministry of Agriculture and Fisheries Grant from Development Fund	9,000 0 0	
Fishmongers' Company	442 10 0	
Royal Society	30 0 0	9,472 10 0
,, Subscriptions		120 3 0
,, Composition Fees		– – –
,, Donations		1 16 6
,, Sale of Specimens (*less* Purchases)		901 3 7
,, ,, Fish (*less* Expenses)		31 19 0
,, ,, Nets, Gear, and Apparatus		88 12 8
,, Table Rent		170 15 0
,, Tank Room Receipts		310 0 6
,, Interest on Investments :—		
4% War Stock	3 2 8	
4% New Zealand Stock	12 6 6	15 9 2

The Association's Bankers hold on its behalf:—
£410 14s. 8d. New Zealand 4% Stock, 1943–63.
£500 0s. 0d. War Savings Certificates.
£78 9s. 4d. 4% War Loan, 1929–42 Registered Stock, 4%.

£12,140 11 7

SPECIAL

CAPITAL

	£ s. d.
To Donations	52 10 0
,, Sale of Steamer *Oithona*	775 0 0
,, Grant from Development Fund	447 17 4
,, Loan ,, ,, ...	145 0 0
	£1,420 7 4

EASTER CLASS

	£ s. d.
To Donations	214 13 6
,, Balance, Amount due to General Fund	153 10 0
	£368 3 6

OF THE UNITED KINGDOM.

Year, 1st April, 1922, to 31st March, 1923. Cr.

FUND.

	£	s.	d.	£	s.	d.
By Salaries :—						
Director	862	10	0			
Physiologist	800	0	0			
Naturalists	2,380	15	5			
Hydrographer	458	6	8	4,501	12	1
,, Laboratory Wages (including National Insurance and Pension)				1,599	8	8
,, Annual Upkeep of Library				293	4	7
,, Scientific Publications :—						
Journal, Vol. XII, No. 4	308	10	7			
Less Sales	11	13	8	296	16	11
,, Annual Upkeep of Laboratories and Tank Rooms :—						
Buildings and Machinery	427	10	3			
Electricity, Gas, Coal, Water	253	4	11			
Chemicals and Apparatus	494	19	2			
Rates, Taxes, and Insurance	71	2	4			
Travelling	108	8	0			
,, Challenger Society Meetings	30	1	9			
Stationery, Postages, Telephone, Carriage, and Sundries	338	8	3	1,723	14	8
,, Annual Maintenance and Hire of Boats :—						
Wages (including Diet Allowance, National Insurance, and Casual Labour)	1,589	11	8			
Coal and Water	541	10	2			
Maintenance and Repairs, with Nets, Gear, and Apparatus	615	8	2			
Boat Hire and Collecting Expeditions	42	11	4			
Insurance	436	18	4	3,225	19	8
,, Interest on Loan				8	1	3
,, Balance :—						
Cash in hand	10	15	9			
Cash at Bank	327	8	0			
Balance from Easter Class Building Fund	153	10	0	491	13	9
				£12,140	11	7

FUND.

EXPENDITURE.

	£	s.	d.
By Balance from 31st March, 1922 :—			
Amount due to General Fund	591	4	3
,, Electrical Installation	198	4	9
,, Physiological Library	63	1	6
,, Outfitting Steam Drifter	16	18	1
,, Balance, Cash at Bank	550	18	9
	£1,420	7	4

BUILDING FUND.

	£	s.	d.
By Expenditure on Building	368	3	6
	£368	3	6

Examined and found correct,

(Signed) W. T. BRAND.
L. D. NICHOLSON.
J. O. BORLEY.
N. E. WATERHOUSE.

3 *Frederick's Place,*
Old Jewry, London, E.C. 2.
24th April, 1923.

List of Annual Subscriptions

Paid during the Three Months, 1st January to 31st March, 1922.

	£	*s.*	*d.*
W. M. Aders, Esq.	1	1	0
J. R. Baker, Esq.	1	1	0
Sir W. M. Bayliss, F.R.S.	1	1	0
Lieut.-Col. T. T. Behrens	1	1	0
H. H. Bloomer, Esq.	1	1	0
Sir John Rose Bradford, K.C.M.G., F.R.S.	1	1	0
R. H. Burne, Esq.	1	1	0
L. W. Byrne, Esq.	1	1	0
G. S. R. Kitson Clarke, Esq.	1	1	0
L. R. Crawshay, Esq.	1	1	0
Commander G. C. C. Damant, R.N.	1	1	0
Prof. O. V. Darbishire	1	1	0
W. C. De Morgan, Esq.	1	1	0
G. Despott, Esq., M.B.O.U.	1	1	0
F. A. Dixey, Esq.	1	1	0
C. Clifford Dobell, Esq., F.R.S.	1	1	0
J. S. Dunkerly, Esq.	1	1	0
Prof. E. S. Goodrich, F.R.S.	1	1	0
Sir Eustace Gurney	1	1	0
Prof. W. D. Halliburton, F.R.S.	1	1	0
W. T. Hillier, Esq., M.R.C.S.	1	1	0
W. E. Hoyle, Esq., D.Sc.	1	1	0
R. Kirkpatrick, Esq.	1	1	0
J. J. Lister, Esq., F.R.S.	1	1	0
Miss D. Jordan Lloyd (1921 and 1922)	2	2	0
Prof. E. W. MacBride, F.R.S.	1	1	0
W. S. Millard, Esq.	1	1	0
The Rev. Canon A. Morford (the late)	1	1	0
C. C. Morley, Esq.	1	1	0
H. G. Newth, Esq.	1	1	0
Carried forward	32	11	0

	£	s.	d.
Brought forward	32	11	0
Chas. Oldham, Esq.	1	1	0
Plymouth Corporation (Museum Committee)	1	1	0
Port of Plymouth Incorporated Chamber of Commerce	1	1	0
J. A. Robertson, Esq.	1	1	0
G. C. Robson, Esq.	1	1	0
J. T. Saunders, Esq.	1	1	0
Edgar Schuster, Esq., D.Sc.	1	1	0
W. L. Sclater, Esq.	1	1	0
Miss L. Sheldon	1	1	0
S. Takeda, Esq.	1	1	0
Sir H. F. Thompson, Bart.	1	1	0
Sir John I. Thornycroft, F.R.S.	1	1	0
Lieut.-Col. H. J. Walton, I.M.S.	1	1	0
Warden of Fisheries, Punjab	1	1	0
W. A. Willes, Esq.	1	1	0
Col. H. A. Williamson	2	2	0
R. Winckworth, Esq.	1	1	0
Total	£51	9	0

List of Annual Subscriptions

Paid during the Year, 1st April, 1922, to 31st March, 1923.

	£	s.	d.
W. M. Aders, Esq.	1	1	0
E. J. Allen, D.Sc., F.R.S.	1	1	0
G. L. Alward, Esq.	1	1	0
Prof. J. H. Ashworth, F.R.S.	1	1	0
J. R. Baker, Esq.	1	1	0
Prof. W. Bateson, F.R.S.	1	1	0
Sir W. M. Bayliss, F.R.S.	1	1	0
W. J. Bazeley, Esq.	1	1	0
Lieut.-Col. T. T. Behrens	1	1	0
Col. H. F. Bidder	1	1	0
Mrs. M. G. Bidder	1	1	0
Carried forward	11	11	0

	£	s.	d.
Brought forward	11	11	0
Birkbeck College	1	1	0
E. J. Bles, Esq., D.SC.	1	1	0
L. A. Borradaile, Esq., SC.D.	1	1	0
Col. Henry Bowles	1	1	0
Sir John Rose Bradford, K.C.M.G., F.R.S.	1	1	0
Brighton Public Library	1	1	0
H. H. Brindley, Esq.	1	1	0
Mrs. E. T. Browne (1922 and 1923)	2	2	0
R. H. Burne, Esq.	1	1	0
L. W. Byrne, Esq.	1	1	0
W. T. Calman, Esq., D.SC., F.R.S.	1	1	0
H. Graham Cannon, Esq.	1	1	0
Prof. Chas. Chilton	1	1	0
J. Clark, Esq., D.SC.	1	1	0
G. S. R. Kitson Clarke, Esq.	1	1	0
J. Omer Cooper, Esq.	1	1	0
L. R. Crawshay, Esq.	1	1	0
H. H. Dale, Esq., C.B.E., F.R.S.	1	1	0
Commander G. C. C. Damant, R.N.	1	1	0
Prof. O. V. Darbishire	1	1	0
W. Cameron Davidson, Esq.	1	1	0
Monsieur J. Delphy		10	0
W. C. De Morgan, Esq.	1	1	0
Prof. A. Dendy, F.R.S.	1	1	0
G. Despott, Esq., M.B.O.U.	1	1	0
Director of Agriculture and Fisheries, Travancore	1	1	0
F. A. Dixey, Esq.	1	1	0
C. Clifford Dobell, Esq., F.R.S.	1	1	0
J. S. Dunkerly, Esq.	1	1	0
Major Ernest Elwes	1	1	0
George Evans, Esq. (1922 and 1923)	2	2	0
W. Edgar Evans, Esq.	1	0	0
G. P. Farran, Esq. (1922 and 1923)	2	2	0
Dr. E. L. Fox	1	1	0
Carried forward	49	16	0

	£	s.	d.
Brought forward	49	16	0
H. M. Fox, Esq.	1	1	0
Prof. F. W. Gamble, F.R.S.	1	1	0
Prof. E. S. Goodrich, F.R.S.	1	1	0
J. Gray, Esq.	1	1	0
Sir Eustace Gurney	1	1	0
Wilfred Hall, Esq.	1	1	0
Prof. W. D. Halliburton, F.R.S.	1	1	0
A. Clavering Hardy, Esq.	1	1	0
Sir W. A. Herdman, C.B.E., F.R.S. (1921 and 1922)	2	2	0
Prof. S. J. Hickson, F.R.S.	1	1	0
Prof. J. P. Hill, F.R.S.	1	1	0
T. V. Hodgson, Esq.	1	1	0
Capt. G. L. C. Howell (1922 and 1923)	2	2	0
J. S. Huxley, Esq.	1	1	0
J. J. Judge, Esq.	1	1	0
Sir Frederick Keeble, C.B.E., F.R.S.	1	1	0
R. Kirkpatrick, Esq.	1	1	0
J. J. Lister, Esq., F.R.S.	1	1	0
H. M. Lomas, Esq. (1922 and 1923)	2	2	0
Capt. W. N. McClean	1	1	0
S. Makovski, Esq.	1	1	0
D. J. Matthews, Esq.	1	1	0
H. G. Maurice, Esq., C.B. (1918–1922)	5	5	0
J. H. Midgley, Esq.	1	1	0
W. S. Millard, Esq.	1	1	0
The Rev. Canon A. Morford (the late)	1	1	0
C. C. Morley, Esq.	1	1	0
H. G. Newth, Esq.	1	1	0
Chas. Oldham, Esq.	1	1	0
Enrique Pascual, Esq., O.B.E.	1	1	0
Rev. C. W. Poignand, R.N. (1921 and 1922)	2	2	0
Port of Plymouth Incorporated Chamber of Commerce	1	1	0
W. P. Pycraft, Esq.	1	1	0
Major G. Raymond	1	1	0
Carried forward	93	18	0

	£	s.	d.
Brought forward	93	18	0
J. A. Robertson, Esq.	1	1	0
E. S. Russell, Esq., D.Sc.	1	1	0
J. T. Saunders, Esq.	1	1	0
R. E. Savage, Esq.	1	1	0
Edgar Schuster, Esq., D.Sc.	1	1	0
W. L. Sclater, Esq.	1	1	0
Major H. Seymour Sewell, I.M.S. (1922 and 1923)	2	2	0
Miss L. Sheldon	1	1	0
Sir Arthur E. Shipley, G.B.E., F.R.S.	3	3	0
Lieut.-Com. R. Spry (1922 and 1923)	2	2	0
S. Takeda, Esq.	1	1	0
Sir H. F. Thompson, Bart.	1	1	0
Sir John I. Thornycroft, F.R.S.	1	1	0
Torquay Natural History Society (1922 and 1923)	2	2	0
Lieut.-Col. H. J. Walton, I.M.S.	1	1	0
A. W. Waters, Esq.	1	1	0
A. T. Watson, Esq.	1	1	0
Mrs. Weldon	1	1	0
W. A. Willes, Esq.	1	1	0
R. Winckworth, Esq.	1	1	0
Total	£120	3	0

Special Fund.

1922	£	s.	d.
Dr. G. P. Bidder	100	0	0
Prof. E. W. MacBride, F.R.S.	1	1	0
1922–23			
Royal Microscopical Society	52	10	0
Total	£153	11	0

Special Donations for Easter Class Building Fund

For the Year, April 1st, 1922, to March 31st, 1923.

	£	s.	d.
The University of London	25	0	0
The University of Leeds	10	10	0
His Honour Judge Chapman	10	10	0
Prof. W. B. Alexander	10	0	0
E. J. Allen, D.Sc., F.R.S.	10	0	0
K. H. Barnard, Esq.	10	0	0
A. D. Pass, Esq.	10	0	0
Fishery Board for Scotland	5	5	0
J. Gray, Esq.	5	5	0
Sir W. M. Bayliss, F.R.S.	5	0	0
G. H. Fowler, Esq., PH.D.	5	0	0
C. F. A. Pantin, Esq.	5	0	0
Prof. A. Willey, F.R.S.	5	0	0
W. E. Evans, Esq.	4	0	0
M. D. Hill, Esq.	3	3	0
Sir Herbert Thompson	3	3	0
T. V. Hodgson, Esq.	3	0	0
The Rt. Hon. Lord Avebury	2	2	0
G. W. Butler, Esq.	2	2	0
L. W. Byrne, Esq.	2	2	0
J. S. Dunkerly, Esq.	2	2	0
G. Evans, Esq.	2	2	0
Mrs. V. Lebour	2	2	0
A. N. Moncrieff, Esq.	2	2	0
F. A. Potts, Esq.	2	2	0
A. M. Carr Saunders, Esq.	2	2	0
J. T. Saunders, Esq.	2	2	0
J. S. Thomson, Esq.	2	2	0
R. S. Clark, Esq.	2	0	0
Prof. E. S. Goodrich, F.R.S.	2	0	0
H. S. Pearson	2	0	0
Carried forward	158	18	0

	£	s.	d.
Brought forward	158	18	0
A. D. Ritchie, Esq.	2	0	0
S. D. Scott, Esq.	2	0	0
Miss Worsnop.	2	0	0
R. A. Todd, Esq.	1	11	6
Prof. W. E. Agar	1	1	0
Miss L. Batten	1	1	0
L. A. Borradaile, Esq., SC.D.	1	1	0
G. Cannon, Esq.	1	1	0
Commander G. C. C. Damant	1	1	0
Prof. O. V. Darbishire	1	1	0
F. M. Duncan, Esq.	1	1	0
F. M. Davis, Esq.	1	1	0
E. Ford, Esq.	1	1	0
Miss Garstang	1	1	0
Sir Sidney Harmer, K.B.E., F.R.S.	1	1	0
C. T. Heycock, Esq.	1	1	0
W. H. Hodgson, Esq.	1	1	0
M. Jeffs, Esq.	1	1	0
Miss D. Jordan Lloyd	1	1	0
Dr. Edith M. Musgrave	1	1	0
Prof. R. C. Punnett	1	1	0
E. S. Russell, Esq., D.SC.	1	1	0
F. S. Russell, Esq.	1	1	0
H. P. Sherwood, Esq.	1	1	0
W. E. Stoneman, Esq.	1	1	0
R. E. Savage, Esq.	1	1	0
S. M. Wadham, Esq.	1	1	0
Prof. J. H. Ashworth, F.R.S.	1	0	0
H. Bennett, Esq.	1	0	0
A. D. Cotton, Esq.	1	0	0
C. S. Elton, Esq.	1	0	0
T. J. Evans, Esq.	1	0	0
Prof. J. C. Ewart, F.R.S.	1	0	0
R. Gurney, Esq.	1	0	0
Carried forward	197	12	6

	£	s.	d.
Brought forward	197	12	6
Prof. Halliburton, F.R.S.	1	0	0
A. C. Hardy, Esq.	1	0	0
E. E. Hodgkinson, Esq.	1	0	0
J. S. Huxley, Esq.	1	0	0
Prof. R. Douglas Laurie	1	0	0
W. H. Leigh-Sharpe, Esq.	1	0	0
F. B. Stead, Esq.	1	0	0
Dr. J. Stephenson	1	0	0
J. H. Taylor, Esq.	1	0	0
A. Vassall, Esq.	1	0	0
Anonymous		10	6
H. Scott, Esq.		10	6
J. C. W. Bannerman, Esq.		10	0
F. E. Beddard, Esq., D.SC., F.R.S.		10	0
Mrs. E. B. Cooper		10	0
C. D. B. Ellis		10	0
Dr. P. C. Esdaile		10	0
Miss Faulkner		10	0
Miss Fell		10	0
L. T. Hogben, Esq.		10	0
W. R. Price, Esq.		10	0
H. Sandon, Esq.		10	0
C. M. Yonge, Esq.		10	0
Miss A. C. Campbell		5	0
Miss A. C. Kohn-Speyer		5	0
Total	214	13	6

Special Donations for Easter Class Building Fund

For the Year commencing April 1st, 1923.

	£	s.	d.
E. T. Browne, Esq.	25	0	0
T. T. Barnard, Esq.	10	0	0
Prof. J. Stanley Gardiner, F.R.S.	10	0	0
Carried forward	45	0	0

	£	s.	d.
Brought forward . .	45	0	0
W. M. Aders, Esq.	5	0	0
Prof. F. W. Gamble, F.R.S.	5	0	0
J. H. Orton, Esq., D.Sc.	2	2	0
Total	57	2	0

Donations for 1922–23	214	13	6
Donations for 1923 (part)	57	2	0
Total	271	15	6

Marine Biological Association of the United Kingdom.

LIST

OF

Governors, Founders, and Members.

1st September, 1923.

* Member of Council. † Vice-President. ‡ President.

Ann. signifies that the Member is liable to an Annual Subscription of One Guinea.

C. signifies that he has paid a Composition Fee of Fifteen Guineas in lieu of Annual Subscription.

I.—Governors.

The British Association for the Advancement of Science, *Burlington House, W.* £700
The University of Oxford £500
The University of Cambridge £500
The Worshipful Company of Clothworkers, 41, *Mincing Lane, E.C.* £500
The Worshipful Company of Fishmongers, *London Bridge, E.C.* ... £16,176
Bayly, Robert (the late) £1000
Bayly, John (the late) £600
Thomasson, J. P. (the late) £970
*G. P. Bidder, Esq., Sc.D., *Cavendish Corner, Cambridge* £2508
*E. T. Browne, Esq., B.A., *Anglefield, Berkhamsted* £535

II.—Founders.

1884 The Corporation of the City of London £210
1884 The Worshipful Company of Mercers, *Mercers' Hall, Cheapside* .....£341 5*s.*
1884 The Worshipful Company of Goldsmiths, *Goldsmiths' Hall, E.C.*..... £100
1884 The Royal Microscopical Society, 20, *Hanover Square, W.*..... £152 10*s.*
1884 The Royal Society, *Burlington House, Piccadilly, W.* £540
1884 The Zoological Society, *Regent's Park, London, N.W.* £200
1884 Bulteel, Thos. (the late) £100
1884 Burdett-Coutts, W. L. A. Bartlett (the late) £100
1884 Crisp, Sir Frank, Bart. (the late)..... £100
1884 Daubeny, Captain Giles A. £100
1884 Eddy, J. Ray (the late) £100
1884 Gassiott, John P. (the late) £100
‡1884 Lankester, Sir E. Ray, K.C.B., F.R.S., 44 *Oakley Street, Chelsea, S.W.* £101
1884 The Rt. Hon. Lord Masham (the late) £100
1884 Moseley, Prof. H. N., F.R.S. (the late) £100
1884 The Rt. Hon. Lord Avebury, F.R.S. (the late) £100
1884 Poulton, Prof. Edward B., M.A., F.R.S., *Wykeham House, Oxford* £105
1884 Romanes, G. J., LL.D., F.R.S. (the late)..... £100
1884 Worthington, James (the late) £100
1885 Derby, the late Earl of £100
1887 Weldon, Prof. W. F. R., F.R.S. (the late) £100
1888 Bury, Henry, M.A., *The Gate House*, 17 *Alumdale Road, Bournemouth West* £100
1888 The Worshipful Company of Drapers, *Drapers' Hall, E.C.*..... £315
1889 The Worshipful Company of Grocers, *Poultry, E.C.* £120
1889 Thompson, Sir Henry, Bart. (the late) £110
1889 Revelstoke, The late Lord..... £100
*1890 Riches, T. H., B.A., *Kitwells, Shenley, Herts* £430
1902 Gurney, Robert, *Ingham Old Hall, Stalham, Norfolk* £106
1904 Shaw, J., K.C., *Kentchurch Court, Hereford* £113
1909 Harding, Colonel W., *The Hall, Madingley, Cambridge* £100
1910 Murray, Sir John, K.C.B., F.R.S. (the late) £100
1912 Swithinbank, H., F.R.S.E., F.R.G.S., *Denham Court, Denham, Bucks.* £100
1913 Shearer, Dr. Cresswell, F.R.S., 4, *Fitzwilliam Road, Cambridge* £100
1913 Heron-Allen, E., F.R.S., F.L.S., F.R.M.S., F.G.S., 33 *Hamilton Terrace, London, N.W.* .....£125 15*s.*
1920 McClean, Capt. W.N., 1, *Onslow Gardens, S.W.*..... £100
1920 Berry, H. Seymour, *Merthyr Tydfil, Glam.* £105
1920 Llewellyn, D. R., *Fairfield, Aberdare, Glam.*..... £105
1921 Harmer, F. W. (the late)..... ..... £100
1923 Worth, R. H., 42 *George Street, Plymouth*.....£115 15*s.*

III.—Members.

1900 Aders, Dr. W. M., *Zanzibar, East Africa* .....£5 and Ann.
1923 Alexander, Prof. W. B., *The University, Perth, Australia* £10
*1895 Allen, E. J., D.Sc., F.R.S., *The Laboratory, Plymouth* .....£10 and Ann.
1889 Alward, G. L., *Enfield Villa, Humberstone Avenue, Waltham, Grimsby* Ann.
1910 Ashworth, Prof. J. H., D.Sc., F.R.S., *The University, Edinburgh* ..... Ann.
1921 Askwith, The Rt. Hon. Lord, K.C.B., D.C.L., 5 *Cadogan Gardens, London, S.W.* 3 ..... £5
†1911 Astor, Viscount, 4, *St. James's Square, London, W.* ..... *C.*
1910 Atkinson, G. T., 43, *Parliament Street, London, S.W.* ..... Ann.

1920 Baker, J. R., *New College, Oxford* ..... *C.*
1923 Barnard, K. H., *South African Museum, Cape Town*..... £10
1923 Barnard, T. T., *King's College, Cambridge* £11
1919 Bateson, Prof. W., F.R.S., *The Manor House, Merton, S.W.* 19 ..... Ann.
1919 Bawcomb, J., "*Knaresboro*," *Rose Walk, Purley, Surrey* ..... Ann.
1884 Bayliss, Sir W. Maddock, D.Sc., F.R.S., *St. Cuthberts, West Heath Road, Hampstead, London, N.W.* 3 .....£15 and Ann.
1884 Bayly, Miss Anna, *Seven Trees, Plymouth* £50
1921 Bazeley. W. J., *The Cliff, Penzance, Cornwall* ..... Ann.
1885 Beck, Conrad, 68, *Cornhill, E.C.* ..... *C.*
1884 Beddington, Alfred H., 8, *Cornwall Terrace, Regent's Park, N.W.* ..... *C.*
†1907 Bedford, His Grace the Duke of, K.G., *Endsleigh, Tavistock* ..... *C.*
1919 Behrens, Lt.-Col. T. T., *United Service Club, Pall Mall, London, S.W.*..... ..... Ann.
1903 Bidder, Colonel H. F., *Ravensbury Manor, Mitcham* ..... Ann.
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OF THE

Marine Biological Association

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THE ASSOCIATION was founded at a Meeting called for the purpose in March, 1884, and held in the Rooms of the Royal Society of London.

The late Professor HUXLEY, at that time President of the Royal Society, took the chair, and amongst the speakers in support of the project were the late Duke of ARGYLL, the late Sir LYON PLAYFAIR, the late Lord AVEBURY, the late Sir JOSEPH HOOKER, the late Dr. CARPENTER, the late Dr. GÜNTHER, the late Lord DALHOUSIE, the late Professor MOSELEY, the late Mr. ROMANES, and Sir E. RAY LANKESTER.

The Association owes its existence and its present satisfactory condition to a combination of scientific naturalists, and of gentlemen who, from philanthropic or practical reasons, are specially interested in the great sea fisheries of the United Kingdom. It is universally admitted that our knowledge of the habits and conditions of life of sea fishes is very small, and insufficient to enable either the practical fisherman or the Legislature to take measures calculated to ensure to the country the greatest return from the "harvest of the sea." Naturalists are, on the other hand, anxious to push further our knowledge of marine life and its conditions. Hence the Association has erected at Plymouth a thoroughly efficient Laboratory, where naturalists may study the history of marine animals and plants in general, and where researches on food-fishes and molluscs may be carried out with the best appliances.

The Laboratory and its fittings were completed in June, 1888, at a cost of some £12,000. Since that time investigations, practical and scientific, have been constantly pursued at Plymouth. Practical investigations upon matters connected with sea-fishing are carried on under the direction of the Council; in addition, naturalists from England and from abroad have come to the Laboratory, to carry on their own independent researches, and have made valuable additions to zoological and botanical science, at the expense of a small rent for the use of a working table in the Laboratory and other appliances. The number of naturalists who can be employed by the Association in special investigations on fishery questions, and definitely retained for the purpose of carrying on those researches throughout the year, must depend on the funds subscribed by private individuals and public bodies for the purpose. The first charges on the revenue of the Association are the working of the sea-water circulation in the tanks, stocking the tanks with fish and feeding the latter, the payment of servants and fishermen, the hire and maintenance of fishing-boats, and the salary of the Resident Director and Staff. At the commencement of this number will be found the names of the gentlemen on the Staff.

The purpose of the Association is to aid at the same time both science and industry. It is national in character and constitution, and its affairs are conducted by a representative Council, by an Honorary Secretary and an Honorary Treasurer, without any charge upon its funds, so that the whole of the subscriptions and donations received are devoted absolutely to the support of the Laboratory and the prosecution of researches by aid of its appliances. The reader is referred to page 4 of the Cover for information as to membership of the Association.

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